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AN ANALYSIS OF THE INHERITANCE OF QUANTITATIVE CHARACTERS, AND LINKAGE IN BARLEY*

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Introduction

Since most agronomic characters of cereal crops are quantitative in their expression, it seems that more attention should be given to quantitative inheritance. The uncertain nature of the results of many studies in quantitative inheritance is due partly to the fact that the samples used are too small. A more important reason, perhaps, is the inclusion of too few characters in individual studies. The segregation of quantitative characters in hybrid samples is very apt to be continuous. In other words clear cut groups do not appear. This is by no means always so, since three of the four size characters included in this study segregated in a discontinuous manner. However, in either case more significant results are obtained in such studies by relating the inheritance of a number of characters, some quantitative and some qualitative.

In studies of this nature it is desirable to publish distributions in individual lines of the characters considered. In the present case the extent of the data makes this impossible.

For a review of the literature on barley genetics, the reader is referred to Hayes and Garber (6) and Robertson, (9). Only results intimately connected with problems discussed herein are cited.

Characters Studied

The material used for this study was derived from a cross between the varieties Guy Mayle and Canadian Thorpe. A study of the F_2 generation was made, and reported in a previous paper (Neatby (7)). Consideration was given to the inheritance of six characters, and the same characters in the F_3 generation formed the basis of this investigation. In all 250 lines were grown, together with 25 rows of each parent sown at regular intervals throughout the nursery. But for one consideration, the F_3 lines would have represented a random sample of the F_2 generation. Heads of the individual F_2 plants were harvested, placed in kraft envelopes and stored in tins. Due to the fact that they were not thoroughly dry, a good deal of moulding and some sprouting took place. In drawing the sample for the F_3 generation sprouted plants were necessarily avoided. Since the hulless plants were relatively free from damage, preferential selection was made in their favor. This is obvious from the excess of hulless lines. The hulled character is

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inherited independently of all others dealt with except outer glume length. The inheritance of outer glume length is considered separately for the hulled, hulless, and segregating classes, while for other characters the F_3 sample may be safely regarded as random. Table 1 shows the parental values for each of the six characters studied, the figures were obtained from material grown with the F_3 generation.

TABLE 1. *Degree of difference between parental varieties for the six characters under discu*

Name	Lateral floret	Adherence of lemma	Days from seeding to heading	Height in inches	Length of 12 internodes of rachis (mm.)	Lengt out glume
Guy Mayle	six-rowed	hulless	54.58 ± .3289	29.56 ± .1792	43.64 ± .1905	23.30 ±
Canadian Thorpe	two-rowed	hulled	63.16 ± .2744	37.52 ± .2069	28.98 ± .1733	11.34 ±
Difference			8.50 ± .4283	7.96 ± .2737	14.66 ± .2575	11.96 ±

The number of lines for which complete data were obtained varies for different characters; when less than ten plants were available for measurement, the line was discarded. The outer glume study suffered most in this respect. The awn of the outer glume is very fragile, and as a result uninjured specimens frequently numbered less than ten in one line. The methods of classification and measurement are described separately for each character in the section devoted to it.

The standard deviation of growth period and height for the parental varieties was calculated by the formula

$$\text{S.D.} = \sqrt{\frac{S\ (x - \bar{x}_p)^2}{S\ (n' - 1)}},$$

when S indicates summation, $x - \bar{x}_p$ is the deviation of an individual plant from the mean of the plot in which it grows, and n' is the number of plants in one plot. This formula eliminates the variance due to plot means, which is important in the study of such characters as height and earliness, since they are markedly affected by varying soil conditions. The average standard deviation of the parents is equal to

$$\sqrt{\frac{S\ (x' - \bar{x}'_p)^2 + S\ (x - \bar{x}_p)^2}{S\ (n_1 - 1)\ +\ S\ (n_2 - 1)}}$$

when x' and x represent individual plant determinations of the two parents, and n_1 and n_2 represent the number of plants in individual plots of the respective parents. This formula makes due allowance for variance between plots, and also for variance between the two parental varieties.

Standard deviations for the characters density and length of outer glume could not be calculated according to the formulae given above, since the plots of the parental varieties were not harvested separately. Instead a random sample of 50 heads was taken from each parent variety, and the standard deviations based on the sample. Such an estimated standard deviation is sufficiently accurate for the characters density and outer glume length as these probably vary little from plot to plot. That this statement is justified is indicated by the very high correlations obtained between F_2 and F_3 data for these characters, as will be shown later.

Characters Considered Independently

Lateral Floret Fertility

The segregation in the F_2 generation indicated a single main factor difference between the six-rowed and two-rowed types. The variability in the proportion of fertile laterals on the plants classified as intermediate was so great that the action of one or more genetic factors was indicated. In a cross between Manchuria and Svanhals, Harlan and Hayes (*4*) identified a factor affecting the fertility of intermediate types, and succeeded in extracting true breeding intermediate lines.

Table 2 shows the breeding behaviour of the 217 F_2 plants for which both F_2 and F_3 data are available. In the F_2 generation the actual proportion of fertile laterals was determined for each plant, and for purposes of tabulation they are arbitrarily separated into low, medium, and high fertility. In the F_3 generation intermediate plants were classed as intermediate (I) and intermediate plus (I+), the latter being almost completely fertile, but bearing no awns, or only short awn points on the lemmas of the lateral florets. An examination of the table reveals three important facts: all six-rowed plants bred true; only 26 of the 53 two-rowed plants bred true; and the degree of lateral floret fertility of the intermediate plants is undoubtedly inherited, and not merely a result of random variation or of environmental influence.

Table 2. *The breeding behaviour of F_2 plants according to lateral floret fertility.*

F_2 clases	Types of segregation in F_3.						
	*2	2, I,	2, I, 6,	2, I, I+,6,	2, I+,6,	6	
Two-rowed	26	15	11	1			53
Intermediate-low	2	8	17	6	1		34
Intermediate-med.		1	4	13	1		19
Intermediate-high			1	36	8		45
Six-rowed						66	66
	28	24	33	56	10	66	217

*2 = two-rowed, I = intermediate, I+ = intermediate plus, 6 = six-rowed.

In all 219 F_3 lines of ten plants or over were classified, and the number of lines falling in each group according to the type of segregation, is recorded in table 3. The proportion of the various types of segregation does not admit of an explanation on the basis of a single intermedium factor. However a fairly good agreement with the actual proportions is obtained if two such factors are assumed to operate. Let A represent the partially dominant factor responsible for differentiating the two-rowed and six-rowed forms, and let b and c represent two recessive complementary factors capable of inducing partial fertility of the laterals in the absence of A. Assume also that b and c when both homozygous are capable of increasing the fertility of plants constituted Aa, resulting in the I+ type. The absence of true breeding intermediate lines is undoubtedly due to the fact that fertility was the sole crit-

TABLE 3. *Observed and calculated frequencies in F_3 classes according to lateral floret fertility.*

F_2 genotype	F_3 class	Observed	Calculated	$\frac{(O-C)^2}{C}$
aaBBCC aaBBCc aaBbCC aaBBcc aabbCC	2	28	23.94	.69
aaBbCc aaBbcc aabbCc aabbcc	2, I, I,	24	30.78	1.49
AaBBCC AaBBCc AaBbCC AaBBcc AabbCC	2, I, 6,	33	47.88	4.62
AaBbCc AaBbcc AabbCc	2, I, I +, 6,	56	54.72	.03
Aabbcc	*2, I +, 6,	11	6.84	2.53
AABBCC AABBCc AABbCC AABbCc AABBcc AABbcc AAbbCC AAbbCc AAbbcc	6	67	54.72	2.76
	P = .0334		χ^2 = 12.12	

*All the two-rowed plants had very well developed laterals, and were probably genetically intermediate.

erion employed in classification. Two-rowed plants were frequently observed that possessed very well developed, though sterile laterals; and furthermore, the large number of two-rowed F_2 plants which segregated in F_3 indicate that genetically intermediate plants were often classified as two-rowed. It is therefore probable that the three or four expected true breeding intermediate lines were placed in the class which includes the lines segregating for the two-rowed and intermediate condition. For this reason the intermediate (I) and the two-rowed and the intermediate (2,I,) classes are grouped together in the calculation of goodness of fit. The observed and calculated frequencies are recorded in table 3. The value of P is .0334, which indicates that the observed frequencies differ significantly from the calculated. When fitted to the theoretical frequencies based on a two factor difference, i.e. one intermedium factor, a χ^2 value of 25.62 is obtained, and a P value of about .00001. It is probable therefore, that the theory advanced is correct, and that the departure of the actual frequencies from the theoretical is in some degree the result of errors in classification, or of minor modifying factors, or both.

Adherence of Lemma

The F_2 results indicated a single factor difference between hulled and hulless, with the hulled condition dominant. All hulless plants bred true in F_3, and of the 127 hulled F_2 plants 47 bred true for the hulled condition and 80 segregated. These figures are in harmony with a single factor explanation.

Earliness and Winter Habit

The distribution of the F_2 plants according to date of heading was approximately normal, and therefore, there was no indication of the number of genetic factors involved. In F_3, 234 lines were available for the study of this character, and the number of plants heading in each line was recorded every three days throughout the heading period. In order to obtain a rough estimate of the extent to which earliness was inherited, the mean date of heading was calculated for each F_3 line, and correlated with the data recorded for the corresponding F_2 plant. A correlation coefficient of $.5953 \pm .0286$ was obtained. Standard deviations of the individual F_3 lines were calculated and arranged in a frequency distribution. The distribution being approximately normal, there was no definite indication of the proportion of homozygous lines. The average standard deviation of the parental varieties was calculated and found equal to 3.12 days. By using this figure as the upper limit of homozygosity, 24 F_3 lines fall into the homozygous class. If three factors were concerned 29 of the 234 lines should be homozygous. As will be shown later this is not a reliable method of determining the number of factors involved, but in this case probably gives a correct result.

In the F_2 generation winter type plants were observed, but not recognized as such; they were thought to be stunted as a result of the attacks of plant pathogenes. However, in the F_3 lines classification into winter and spring types was readily effected; and of the 234 lines 79 segregated for winter and spring habit of growth; and three lines bred true for winter habit, one of which is illustrated in figure 1. In the segregating lines the date of heading was recorded on all spring type plants, and the number of winter type plants noted.

If three factors in the recessive condition are considered necessary for the winter habit of growth, 96 of the 234 lines should contain some winter type plants. The total number of plants in each line varied from ten to about 80, with an average of from 40 to 50. About one third of the segregating lines would segregate in a 63:1 ratio if three factors were concerned; and hence some F_2 plants heterozygous for all three factors would fail to produce winter plants among their offsprings. In view of this fact 79 segregating lines is a fair approximation of the expected 96.

The question of the relationship between winter habit factors and the relative earliness of spring type plants is of considerable interest. In a cross between Marquis and Kanred wheats Aamodt (*1*) obtained results which indicate that there are two main factors concerned in habit of growth, and two more distinct factors influencing the earliness of spring type plants. The winter habit factors were also concerned in the relative earliness of spring type plants. A similar relationship is apparent in the material under

Figure 1. F_3 lines of the cross Guy Mayle X Canadian Thorpe; left, homozygous winter habit; right, spring habit.

discussion. The F_2 plants which segregated in F_3 for growth habit were 1.17 $\pm$ .28 days later than the F_2 plants which bred true to spring habit. In F_3 the difference was more striking. The lines which segregated (considering only spring type plants) were later than those which bred true for spring habit by 5.75 $\pm$ .32 days. The cause of the greater differenece in F_3 becomes clear from a consideration of the segregation of the earliness factors. In general F_2 plants destined to produce winter type plants in their progenies will be heterozygous for a larger number of earliness factors than will F_2 plants which breed true for spring habit. For example, let X, Y and Z represent three dominant factors for earliness. Then an F_2 plant constituted XxYyZz will be as early as a plant constituted XXYYZZ. The mean of the F_3 plants derived from the heterozygous plant will, however. be considerably later than the mean of those derived from the homozygous early plant. This is an extreme example, but the reasoning is valid for the sample as a whole.

The number of plants in each F_3 line was not sufficiently great to determine individual ratios. In order to determine whether more than one of the winter habit factors affected the earliness of spring plants, the actual proportion of winter plants was calculated for each line. The figures thus obtained were correlated with the earliness of the F_2 parents. A correlation coefficient of $-.4053 \pm .0734$ was obtained showing a negative relation between the proportion of winter plants in the F_3 lines and the earliness of the F_3 plants from which they were derived. This indicates that more than one of the winter habit factors are concerned in the growth period of the spring plants. The relative magnitude of the standard deviations calcu-

lated for segregating and homozygous lines is also enlightening. The lowest standard deviation obtained for a segregating line was 3.47 days, and only two had a standard deviation of less than 4.00. Thus all lines homozygous for earliness, (i.e. S.D. = 3.12 or less) were true breeding spring habit lines. This indicates that all three winter habit factors affect earliness also. If the average parental standard deviation is used as a criterion of homozygosity, it is more likely to indicate too many, than too few factors. In the present instance the operation of three factors is indicated. It is therefore probable that Guy Mayle and Canadian Thorpe differ by three main factors for growth period; and when these three factors are in the homozygous recessive condition winter habit results. Canadian Thorpe probably carries two and Guy Mayle one. The transgressive segregation is also indicative; there was a large number of lines earlier than Guy Mayle, but none later than Canadian Thorpe. This is in keeping with the theory advanced, since all lines genetically later than Canadian Thorpe would develop the winter habit of growth.

Height of Plant

Complete data were obtained on height of plant for 228 lines, and the mean value and standard deviation were calculated for each line. The results do not lend themselves very well to a factorial explanation. Table 4 contains the distribution of the means. The distribution shows a bimodal tendency, but this probably has no significance since it is difficult to conceive of any factorial condition that would give rise to such an equal division of the sample.

TABLE 4. *Distribution of mean heights of 228 F_2 lines.*

Height in inches	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41
Frequencies	2	4	7	14	17	25	22	29	11	28	27	16	10	7	3	4	2

The distribution of the standard deviations was approximately normal, and so afforded no clue to the number of homozygous lines. The average standard deviation of the parental varieties was 2.04; of the 228 F_3 lines 12 fell at or below this level. If four independently inherited factors were concerned, 14 homozygous lines would be expected. A correlation coefficient of .4977 $\pm$ .0368 between the F_2 plants and corresponding F_3 means was obtained; which is a considerably lower figure than was obtained in the case of earliness. This fact together with the proportion of probably homozygous lines suggests that the difference in height between Guy Mayle and Canadian Thorpe is governed by at least four pairs of factors.

Density of Spike

Complete data were obtained on 218 F_3 lines. At harvest one head was taken from each plant and the heads of each line put together in a kraft envelope for storing. The length of 12 internodes of the rachis was determined for each head. The mean, standard deviation, and coefficient of variability were determined for each line.

In a study of the inheritance of seed length in an oat cross, Quisenberry (*8*) has used the coefficient of variation of F_3 lines as a criterion of homozygosity. He points out that this method can be expected to give only a

rough estimate of the number of genetic factors concerned in the inheritance of a size character. In the present instance the average standard deviation of the parental varieties was 1.19 mm. Of the 218 F_3 lines 30 fell at or below this level. On the basis of three independently inherited factors 27 homozygous lines would be expected; thus the operation of three factors is indicated. That this conclusion is erroneous is shown by the following analysis.

The distribution of the standard deviations of the F_3 lines was clearly bimodal and the numbers falling in each group were about equal. This strongly suggests a single main factor difference. Table 5 shows the distribution of the means for values of the standard deviation above and below 3.0. The mean value for Canadian Thorpe was 28.98, and the mean for the dense group in the table is 29.24; the Guy Mayle mean was 43,64, while the mean for the lax group in the table is 41.69. It is obvious that a few lines are wrongly placed in the table, yet when this grouping is fitted to a 1:2:1 ratio a P value of .1721 is obtained. Figure 2 illustrates the distribution according to means and standard deviations. There are three very obvious swarms; one homozygous dense, one homozygous lax, and one heterozygous intermediate. While it is fully recognized that the delineation of the swarms is to some extent arbitrary, and that the essential feature is the definite swarming, yet it is interesting to apply the χ^2 test. In the present instance a P value of .1985 is obtained when the numbers are fitted to a 1:2:1 ratio. It is clear from the figure that the lax group has a somewhat higher mean standard deviation than has the dense group. This fact justifies placing the upper limit of the heterozygous swarm rather higher on the left, which accounts for the apparent robbery of the dense group.

The higher standard deviation of the lax group suggests the advisability of using the coefficient of variability for analyses of this kind. Figure 3

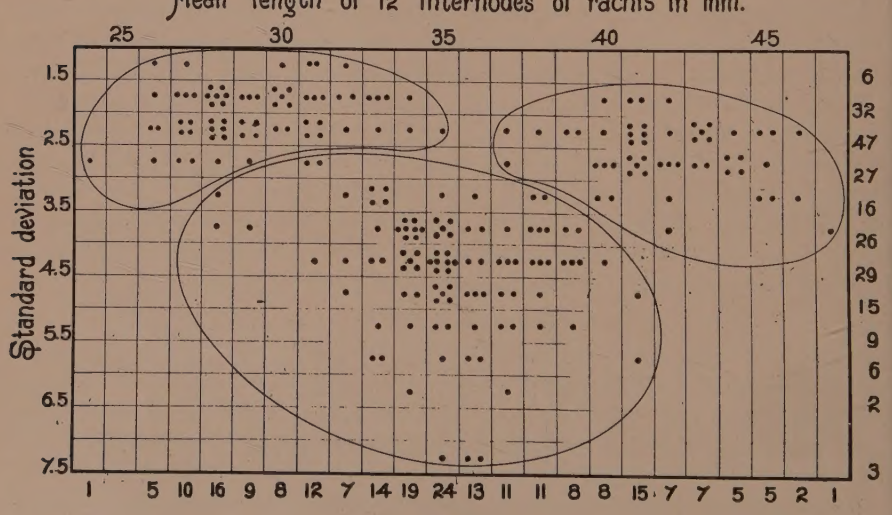

Figure 2. Distribution of F_3 lines according to the mean and standard deviation of the density of the spike.

TABLE 5. *Distribution of F_3 lines according to mean density for high and low values of the standard deviation.*

	Mean Density																							
	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47
S.D.<3.0	1		5	10	14	8	8	9	4	4	2	1		2	1	2	5	12	5	6	5	3	1	
S.D.>3.0					2	1		3	3	10	17	23	13	9	10	6	3	3	2	1		2	1	1

shows the distribution for the same material when the coefficient of variability is substituted for the standard deviation. In this case the lax group in general has a lower coefficient than has the dense group, the swarming is rather less well defined, and a large proportion of the probably homozygous dense group has a higher coefficient of variability than part of the heterozygous group. The result of this comparison favours the use of the standard deviation rather than the coefficient of variability, at least for this material; for this reason the former constant is used throughout this investigation.

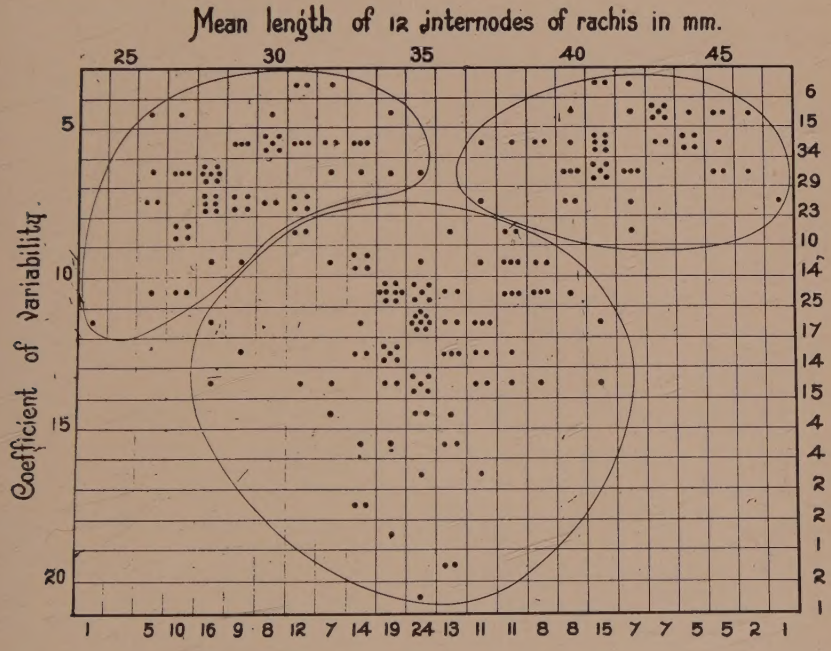

Figure 3. Distribution of F_3 lines according to the mean and coefficient of variability of the density of the spike.

While these results indicate that a single factor pair is responsible for the difference in density between Canadian Thorpe and Guy Mayle, subsidiary factors probably operate also. As was pointed out above, only 30 lines had a standard deviation equal to or less than the average parental value. This implies that two or more factors are operating; but in view of the data presented it seems probable that one factor is concerned chiefly and that minor modifiers are also present.

That density is a particularly favorable character for a study of this kind is indicated by the correlation between F_2 plants and F_3 means; a value of .8707 ± .0111 was obtained.

Results of other workers agree very well with the data presented here. Hayes and Harlan (5) made an extensive study of the inheritance of density in different crosses. In some cases a single factor difference was indicated, while other results were explained on a multiple factor basis. Similar conclusions may be drawn from data presented by Biffen. (*2*).

Length of Outer Glume

Results obtained from a study of the F_2 generation, and published in a previous paper (*7*) indicated that the inheritance of outer glume length was governed by two factors. The expression of one of the factors appeared to be inhibited by the action of the factor responsible for hulled seed.

In the F_3 generation measurements of ten plants or more were obtained from 203 lines. The mean value and standard deviation were calculated for each. That outer glume length is exceptionally stable for a size character is indicated by the correlation between the F_2 plants and corresponding F_3 means; a coefficient of .9039 ± .0090 was obtained.

Figure 4 illustrates the relationship between the mean values and the standard deviations. As in the case of density, the individual lines fall into three fairly well defined groups. However, as was stated in a previous section the inheritance of outer glume length must be studied separately for the hulled and hulless groups. This is due to the fact that the expression of the factors for outer glume length is not independent of the factors for hulled and hulless seed and the sample is not random for the latter characters.

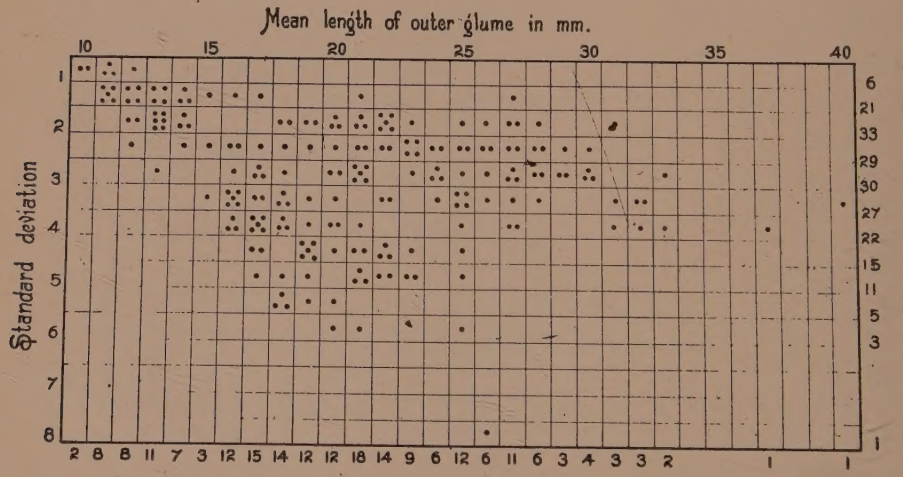

Figure 4. Distribution of F_3 lines according to the mean value, and standard deviations of outer glume length.

When the hulled, segregating, and hulless lines are separately arranged according to the means and standard deviations, the grouping is not sufficiently clear to admit of a factorial explanation for all groups. However, in each case there is a well defined "short" group, and the interpretation is,

therefore, based on the relative size of these groups. The distributions according to the mean value are recorded in table 6. In the hulled group the separation should obviously be made at class 14, and it is equally obvious that class 15 is the dividing line for the hulless group. In the segregating group, the one individual falling in class 15 was considered short.

The explanation offered for the above results is based on the following assumptions: firstly, that Guy Mayle carries a dominant lengthening factor (L) which is expressed independently of the hulled vs. hulless factor pair; and secondly, that Canadian Thorpe carries a recessive lengthening factor (l′) the expression of which is inhibited by the action of the factor for hulled seed. The expected classes and frequencies, based on this theory are given in table 7. The agreement between the observed and calculated frequencies may be tested in two ways; namely by the χ^2 test, or by the deviations from the expected ratios in the hulled, etc. groups. When the χ^2 test is applied a P value of .1188 is obtained, which implies a fairly good fit. If the ratios of long glumes to short glumes are considered separately in the hulled, etc. groups, a fairly good agreement between observed and calculated frequencies results. In the hulled group the deviation from a 3:1 ratio divided by the probable error is 1.32. In the segregating group Dev./P.E. (12:4 ratio) is 2.51 and in the hulless group Dev./P.E. (13:3 ratio) is 2.19.

TABLE 7. *F_2 lines grouped according to outer glume length, and adherence and non-adherence of lemma.*

F_2 genotype	Adherence of lemma	Outer glume	Observed	Calculated	$\frac{(O-C)^2}{C}$
*HHL′L′LL HHL′l′LL HHl′l′LL HHL′L′Ll HHL′l′Ll HHl′l′Ll	Hulled	long	29	31.5	.20
HHL′L′ll HHL′l′ll HHl′l′ll	Hulled	short	13	10.5	.60
HhL′L′LL HhL′l′LL Hhl′l′LL HhL′L′Ll HhL′l′Ll Hhl′l′Ll	Segregating	long	65	58.5	.72
HhL′l′ll HhL′L′ll Hhl′l′ll	Segregating	short	13	19.5	2.17
hhL′L′LL hhL′l′LL hhl′l′LL hhL′L′Ll hhL′l′Ll hhl′l′Ll hhl′l′ll	Hulless	long	71	65.8	.41
hhL′l′ll hhL′L′ll	Hulless	short	10	15.2	1.78
			P = .1188	χ^2 = 5.88	

*HH = hulled, l′ = lengthening factor inhibited by H.

TABLE 6. *The distribution of F_3 lines for mean outer glume length, for the hulled, hulless, and segregating classes.*

	MEAN LENGTH OF OUTER GLUME (mm.)																														
	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
Hulled			5	4	4		2	3	4	3	1	4	5	2	2			1			1				1							
Segregating		2	2	1	4	3	1	7	6	4	7	6	7	8	1	5	4		4	2		1		2								1
Hulless			1	2	3	4		2	5	7	4	2	6	4	6	1	7	5	7	3	3	3	3	1	1				1			
Guy Mayle												2	3	10	15	10	6	3			1											
Can. Thorpe	2	12	16	10	7	3																										

TABLE 8. *Showing the relationship bewteen the six characters under study.*

	Lateral floret	Adherence of lemma	Density of spike	Earliness	Height of plant	Length of outer glume
Lateral floret		P=.1957	Linked	P=.1000 (?)	P=.0007	P=.0091
Adherence of lemma	—		P=.3004	P=.1449	P=.9330	P=.0003
Density of spike	+	—		P=.9358	P=.0000	r=—.3247±.0430
Earliness	+	—	+		r=.4559±.0344	r=—.4907±.0363
Height of plant	+	—	+	+		r=—.5477±.0335
Length of outer glume	+	—	+	+	+	

This interpretation is identical with that offered to explain the behaviour in F_2, except that in the latter case both lengthening factors were considered dominant. However, since the assumption that the factor carried by Canadian Thorpe is recessive in no way affects the agreement in F_2, the explanation offered here is probably correct.

Correlated Inheritance

Varieties of cultivated barley have, according to Griffee (*3*), only seven pairs of chromosomes. Since the present study involves at least eleven genetic factors, a number of linkages are to be expected. The relationship between the different characters was determined for all possible combinations. The following criteria were used; (1) mean difference, (2) correlation coefficient, and (3) χ^2 test. The results are summarized in table 8. Linkage is indicated by a significant value of the correlation coefficient, or by an insignificant value of P. When all available information is considered, and the results explained on the basis of the theory of the linear arrangement of genes in the chromosomes, interesting, if somewhat speculative, conclusions result. In the lower left hand section of the table a plus sign implies that the linkage of the characters concerned is due to the location of the causal factors in the same chromosome pair. A minus sign implies that if a relationship exists it is a result of some other cause. These results may now be discussed in some detail.

The case of adherent or non-adherent lemma is readily disposed of; this character was apparently inherited independently of all others except outer glume length. As was explained in a previous section this association is probably due to the inhibitory action of the factor for adherent lemma. Space limitation necessitates the exclusion of most of the tables from which the P values were obtained. However the numbers were adequate, and in every case the grouping was such that 5 was the minimum number in any one cell.

Lateral floret fertility is linked with several characters. Table 9 shows the relationship with density. Were these characters inherited independently, the segregation for density of spike in each lateral floret class should approximate a 1:2:1 ratio. There is only one lax line in the 2 and 2,I, classes; this line has a mean value of 37.0 mm. and a standard deviation of 3.0 mm. By referring to Figure 2 it will be observed that this line is on the borderline between the homozygous lax and heterozygous swarms. It is, therefore, not improbable that this line is really heterozygous for density. If this association was due to a close linkage between the factors for density and two-rowed, there should be a corresponding deficiency of dense six-rowed lines. If, on the other hand, it was due to the inhibitory action of the two-rowed factor on the expression of the factor for laxity, the segregation in the six-rowed class should be according to a 1:2:1 ratio—which it manifestly is not. If the 2 and 2,I, lateral floret classes are combined, the method of determining cross-over percentages described by Griffee (*3*) may be employed. By this method a cross-over percentage of 22 is obtained. Frequencies calculated on this basis give a good agreement in the 2 and 2,I, class, but do not agree in the six-rowed class. Furthermore the fit in the 2 and 2,I, class depends largely upon the single lax individual, the position

of which, as pointed out above is doubtful. The relationship of these two characters to others throws some light on the question. When the relationship of the two-rowed character with outer glume length is determined by the χ^2 method a P value of .0091 is obtained. If the relationship is determined for the hulled group only, $\chi^2 = .78$, and P is about .70. These figures clearly indicate that the factor for two-rowed is linked with the outer glume factor which is inhibited from expression by the factor for hulled seed. In a later paragraph it will be shown that density bears a similar relation to outer glume length. These relationships are easily explained by the assumption that the factors for density two-rowed, and one pair of the outer glume factors are all located in one chromosome pair.

The P value of .1000 would indicate that the six-rowed condition is independent of earliness. If, however, the mean earliness for the two- and six-rowed classes are compared, a relationship is established. The six-rowed lines are earlier than the two-rowed by $3.17 \pm .66$ days.

That lateral floret fertility and height are associated in inheritance is indicated by the P value of .0007. The two-rowed lines were taller than the six-rowed; the mean difference being $2.68 \pm .28$ inches. A similar difference was established in the F_2 generation. It may be mentioned here that Griffee (*3*) established a linkage between earliness and six-rowed, and Tedin (*10*) demonstrated a linkage between height and two-rowed.

Density is apparently inherited independently of earliness, P being equal to .9358. The fact that both characters are linked with lateral floret fertility may be explained by supposing the density factor and the earliness factor concerned to be located near opposite ends of the chromosome.

TABLE 9. *Illustrating the relationship between lateral floret fertility and density of spike.*

	Lateral floret fertility — F_3 classes.						
	2	2,I,	2,I,6,	2,I,I+,6,	2,I+,6,	6	Total
Dense	17	13	8	13	3	11	65
Segregating	10	10	17	32	1	30	100
Lax	-	1	7	11	7	25	51
Total	27	24	32	56	11	66	

TABLE 10. *Showing the relation between density of spike and height of plant of F_3 lines.*

	Height in Inches		
	23 - 30	31 - 34	35 - 41
Dense	34	21	10
Segregating	26	47	27
Lax	7	19	26

$\chi^2 = 30.04$ P = .0000

The striking relationship between density and height is illustrated in table 10. The relationship is, however, negative while a positive relation would be expected; this apparent inconsistency is discussed, and an explanation offered at the end of this section.

Lateness and height are clearly linked in inheritance. The value of $r = .4559 \pm .0344$ was obtained by correlating the mean height and mean earliness of the F_3 lines.

Particularly significant conclusions may be drawn from a study of the relation of outer glume length with other characters. The inhibitory action of the factor for hulled seed makes it possible to determine which of the two outer glume factors is concerned in a particular linkage. Thus if the outer glume factor carried by Guy Mayle is concerned in a given linkage, it should be demonstrable in the hulled group, but if the factor carried by Canadian Thorpe is concerned, segregation is independent in the hulled group. The correlation coefficients contained in table 11 indicate the relation between outer glume length and the three characters, density, height, and earliness in the groups based on hulled or hulless seed.

Figure 5 shows the scatter of F_3 lines according to density and outer glume means. In this case $r = -.3247 \pm .0430$. It appears, therefore, that the factor for density is linked with a factor for long outer glume. Since Canadian Thorpe, the dense parent, has short outer glumes, the linkage must be concerned with the factor which is inhibited by hulled. The figures in Table 11 show that the correlation in the hulled group is probably not significant, r being about 2.5 times its probable error. In the hulless group, however, the correlation is considerably higher than for the total. As noted previously this affords strong evidence for the factors concerned in lateral floret fertility and density being located in the same chromosome pair.

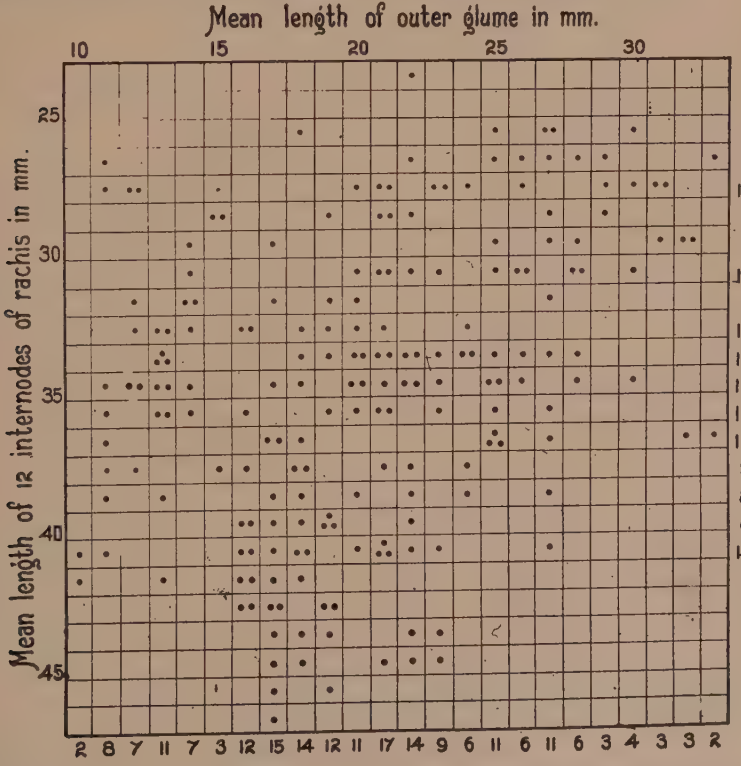

Figure 5. Showing the relation between mean density and mean outer glume length of F_3 lines.

The relationship of outer glume length with height of plant is entirely different. Guy Mayle is the short parent, and the outer glume factor carried by it is expressed independently of the factor for hulled. Figure 6 shows the distribution of all F_3 lines for which complete data were obtained, according to outer glume length and height. In this case, since only one factor operates in the hulled group a higher correlation is to be expected. The figures are given in Table 11, and are strikingly consistent with the theory advanced. One of the height factors together with this outer glume factor therefore constitute a second linkage group.

TABLE 11. *Correlation coefficients for outer glume and density, earliness, and height.*

	Hulled	Segregating	Hulless	Total
Density	—.2482±.0988	—.2828±.0712	—.4549±.0598	—.3247±.0430
Height	—.6241±.0635	—.5607±.0527	—.5313±.0545	—.5477±.0335
Earliness	—.6644±.0596	—.4825±.0590	—.4004±.0637	—.4907±.0363

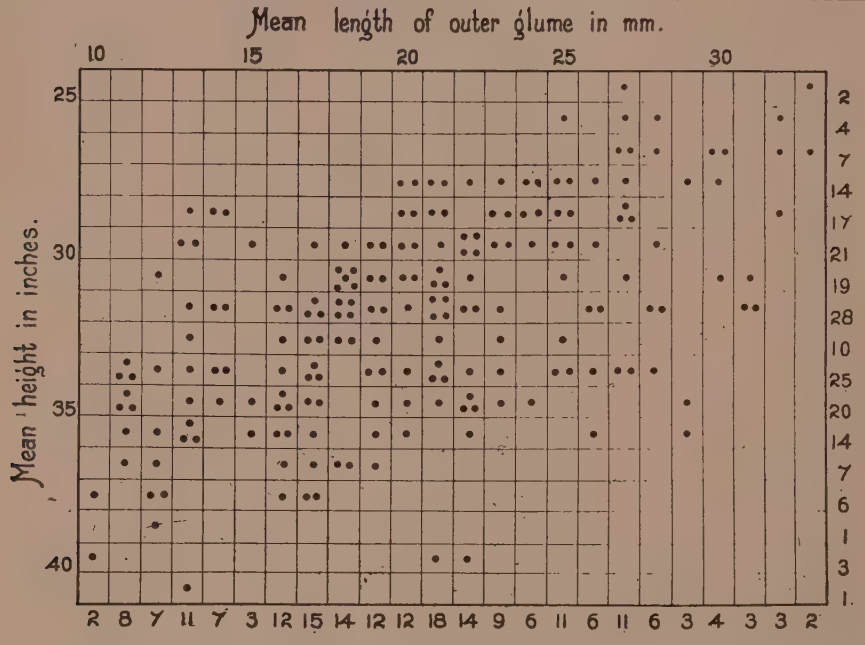

Figure 6. Showing the relation between mean outer glume length and mean height of F_3 lines.

Figure 7 illustrates the relation between outer glume length and earliness. That the linkage in this case is also with the outer glume factor carried by Guy Mayle is obvious from the figures in table 11. Again the correlation is much higher in the hulled group, where only one outer glume factor is operating.

In view of the fact that there are three factors concerned in the inheritance of earliness in this case, and probably at least three for height, a correlation coefficient of .4559 ± .0344 (see previous paragraph) between these two characters is rather surprising. It is particularly so when it is considered that both of these characters are very subject to environmental modification. The high value of the coefficient obtained is readily explained in the light of

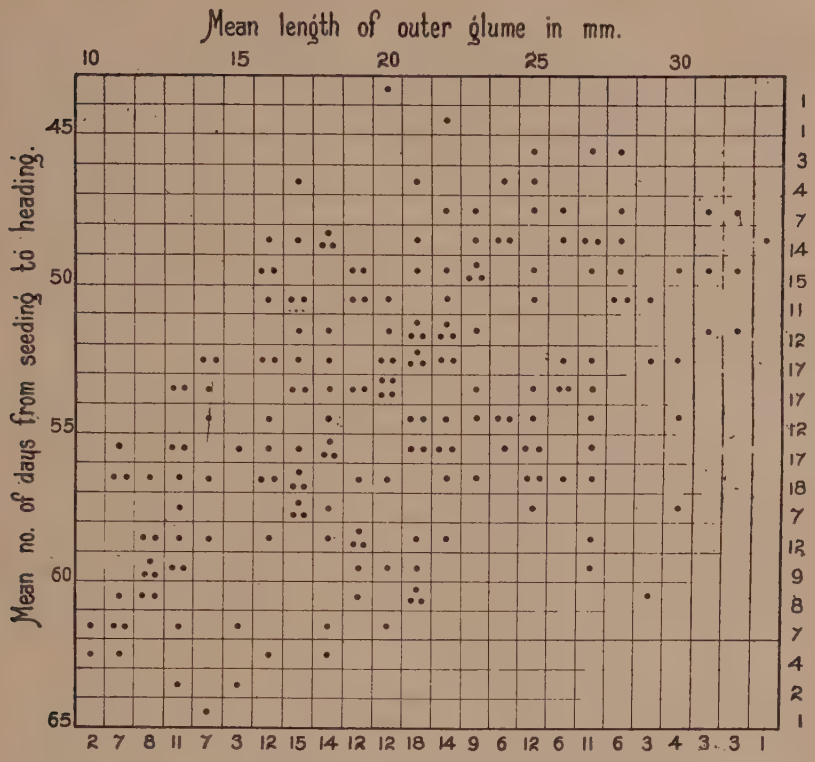

Figure 7. Showing the relation between mean outer glume length and mean earliness of F_3 lines.

the linkage groups established, since each of the two groups contains one height and one earliness factor.

The results of the linkage studies may be summarized as follows: *Group I.* contains the following character pairs: ewo- vs. six-rowed, dense spike vs. lax spike, early heading vs. late heading (one factor), tall vs. short plants (one factor), and long vs. short outer glume (one factor). *Group II.* Tall vs. short (one factor), early heading vs. late heading (one factor) and long vs. short outer glume (one factor). *Group III.* Hulled vs. hulless seed.

When all relationships are considered, this grouping appears inevitable, and harmonizes well with the chromosome theory of heredity. There is, however, one apparent inconsistency. According to the proposed location of factors in Group I, the relation between density and height should be negative; i.e. dense plants should tend to be tall; that the reverse condition obtains is clear from table 10. The obvious effect of the density factor is a shortening of the rachis internodes, and it seems quite possible that it may have a similar effect on the internodes of the culm. It is suggested therefore that Canadian Thorpe (dense and tall) carries a number of height factors one of which is located in the same chromosome pair as the factors for density and two-rowed; but that the shortening effect of the density factor is sufficiently pronounced on the culm to reverse the expected linkage between density and height.

Summary

1. In a cross between the barley varieties Guy Mayle and Canadian Thorpe the inheritance of the following character pairs is described: Two-rowed

vs. six-rowed, hulled vs. hulless, early vs. late, tall vs. short, dense vs. lax spike, and short vs. long outer glume.

2. The difference between the two-rowed and the six-rowed condition in this cross is governed by a single genetic factor. Two factors operate to modify the degree of lateral floret fertility of intermediate types. These factors are also capable of inducing partial fertility in plants homozygous for the two-rowed factor.
3. The difference between hulled and hulless seed is controlled by a single factor pair.
4. It is concluded that three factors are concerned in the inheritance of earliness. When all three factors are in the homozygous recessive condition the plants develop the winter habit of growth.
5. Density of spike is governed by a single main factor; but the relatively high standard deviation of individual F_3 lines indicates that modifying factors operate also.
6. The number of factors concerned in the inheritance of height is not clear. If the average standard deviation of the parental varieties is employed as a criterion of homozygosity the operation of four factors is indicated.
7. The inheritance of outer glume length is governed by two factors. One factor is incapable of expression in hulled plants and is probably carried by Canadian Thorpe, which has short glumes. The other factor is expressed independently of the factors for hulled vs. hulless seed.
8. All possible relationships between the six character pairs are determined. Three linkage groups are identified, one involving five gentic factors one three, and the hulled vs. hulless character pair constitutes a third. This leaves one earliness factor and probably two height factors not accounted for, so that at least four linkage groups are established in this cross.

Acknowledgement

Dr. C. H. Goulden, Senior Cereal Specialist at the Dominion Rust Research Laboratory, has given invaluable advice and criticism in connection with the interpretation of the results, and the arrangement of the text. This assistance is gratefully acknowledged.

LITERATURE CITED

1. Aamodt, O. S. A study of growth habit and rust reaction in crosses between Marquis, Kota and Kanred wheats. Phytopath. *17*: 573-609, 1927.
2. Biffen, R. H. The hybridization of barleys. Jour. Agr. Sci. *2*: 183-206,1907.
3. Griffee, F. Correlated inheritance of botanical characters in barley, and manner of reaction to *Helminthosporium sativum*. Jour. Agr. Res. *30*: 915-935, 1925.
4. Harlan, H. V. and H. K. Hayes. The occurrence of the fixed intermedium *Hordeum intermedium haxtoni* in crosses between *H. vulgare pallidum* and *H: distichon*. Jour. Agr. Res. *19:* 575-591, 1920.
5. Hayes, H. K. and H. V. Harlan. The inheritance of the length of internode in the rachis of barley spike. U.S.D.A. Bulletin 869, 1920.
6. Hayes, H. K. and R. J. Garber. Breeding crop plants. McGraw-Hill Book Co., New York, 1927.
7. Neatby, K. W. Inheritance of quantitative and other characters in a barley cross. Sci. Agr. *7*: 77-84, 1926.
8. Quisenberry, K. S. Correlated inheritance of quantitative and qualitative characters in oats. W. Va. Agr. Exp. Sta. Bulletin 202.
9. Robertson, D. W. Linkage studies in barley. Genetics *14*: 1-36, 1929.
10. Tedin, Hans and Olaf. Contributions to the genetics of barley. I. Type of spike, nakedness, and height of plant. Hereditas, Band VII, Haft II. 1926.

FIELD PLOT TECHNIQUE WITH POTATOES WITH SPECIAL REFERENCE TO THE LATIN SQUARE*

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Much attention has been given in recent years to the question of improved methods of conducting field plot tests with a view to reducing the error due to soil variability. Many contributions have been published on this subject and rapid progress has been made in the study and application of better experimental technique. The publication of another paper showing the value of replication and the advantages of refinement in experimental methods might be regarded as superfluous were it not that the results in the present instance have been obtained with potatoes, a crop which has received much less attention in this respect than have the cereals. Studies in field plot technique with potatoes have been comparatively few, and with the one exception referred to in the literature review, no results of work on experimental methods with this crop have appeared in Canada so far as the writer is aware.

In this study consideration has been given to the value of replication in reducing experimental error, size of plot in relation to the number of replications, and the variability of yields when the plots in each replication series follow the usual systematic distribution as compared with the result when they are arranged at random in a Latin Square. Formulae adapted to machine calculation have been suggested which have been found to facilitate the work of making the necessary mathematical determinations from Latin Square data. An illustration also is given of the "Variance" method of yield analysis as applied to the Latin Square.

Literature Review.

The effect of replication and increasing the size of plots in field tests with potatoes has been studied by Krantz, Meyers and Perry, and Westover. Krantz (*4, 5*) found that greater accuracy was obtained on one-half the amount of land by replication of row plots than could be had by increasing their length. Four systematically distributed two rod rows gave a smaller co-efficient of variability than single rows sixteen rods in length.

Meyers and Perry (*6*) conducted an extensive experiment during two years with different varieties and strains of potatoes. The plots consisted of rows three feet apart with tubers planted in hills eighteen inches apart in the row. These authors concluded that a twenty-five hill row plot replicated ten times should be used, although five replications gave a fair degree of reliability under the conditions of the experiment.

Westover (*8*) made a study of the variability of potato yields for single row plots of different lengths from ten to one hundred and fifty feet and

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for different numbers of replications from one to seven. He found that sufficient accuracy could be secured from the use of forty-foot single row plots replicated four times. Beyond these limits there was no practical reduction in experimental error.

In a statistical study of a yield test of potato varieties Kirk and Goulden (*3*) found a close agreement between the actual and theoretical probable errors in percent for single plots and the means of 2, 3, 5 and 7 systematically distributed plots. The potatoes were grown in rod rows. It was concluded that at least seven replicates were necessary in order to obtain a reliable test.

Experimental Methods.

The experimental field consisted of a piece of land one hundred and thirty-two feet wide and three hundred feet long. This was planted to a uniform strain of Early Ohio potatoes, one seed piece to a hill, the latter being spaced two feet apart in the row and three feet between rows. Ninety-six consecutive rows, each one hundred and thirty-two feet long were available for this study and these were harvested in units of twenty-two feet. There were therefore six units in each row plot. By combining the yields of two, three and six of these, the yield figures for plots 44, 66 and 132 feet long were obtained.

All comparisons have been made on the basis of twenty-four determinations. There being ninety-six rows in all, the value of replication could be investigated by comparing the variability of twenty-four single plot yields with that of the mean yields of two and four systematically distributed plots. The co-efficient of variability was used throughout as a measure of the variability.

It has been pointed out by Hayes and Garber (*2*)that, in practically all studies which have been made of plot size and replication in relation to experimental error, the entire area has been used in comparing the variability of yields from plots of different sizes and different numbers of replicates, whereas in practice more land is required for large plots than for small plots. An increase in area usually means an increase in the variability as well. When all of the plots in the field, regardless of size, are included in each calculation of the coefficient of variability, the comparison becomes somewhat less favourable for small plots than would be the case in actual practice.

Wilcox (*9*) made a study of field plot technique with strawberries in which the area required for different sized plots was taken into account. Instead of calculating the co-efficient of variability from all of the smaller sized plots in the field, he calculated it for a limited number of determinations of plots of a given size. If these occupied only one-quarter of the total area, the constant was calculated also for the same number of determinations and the same sized plot on each of the other three-quarters. The four coefficients thus obtained were averaged and this average used as a basis with which to compare the variability of yields from plots of a different size and with more or fewer replicates. The method used by Wilcox takes care of the point raised by Hayes and Garber fairly well and probably comes as near to giving comparable results as can be expected. Essentially the same method has been followed in analysing the results obtained in this study with potatoes.

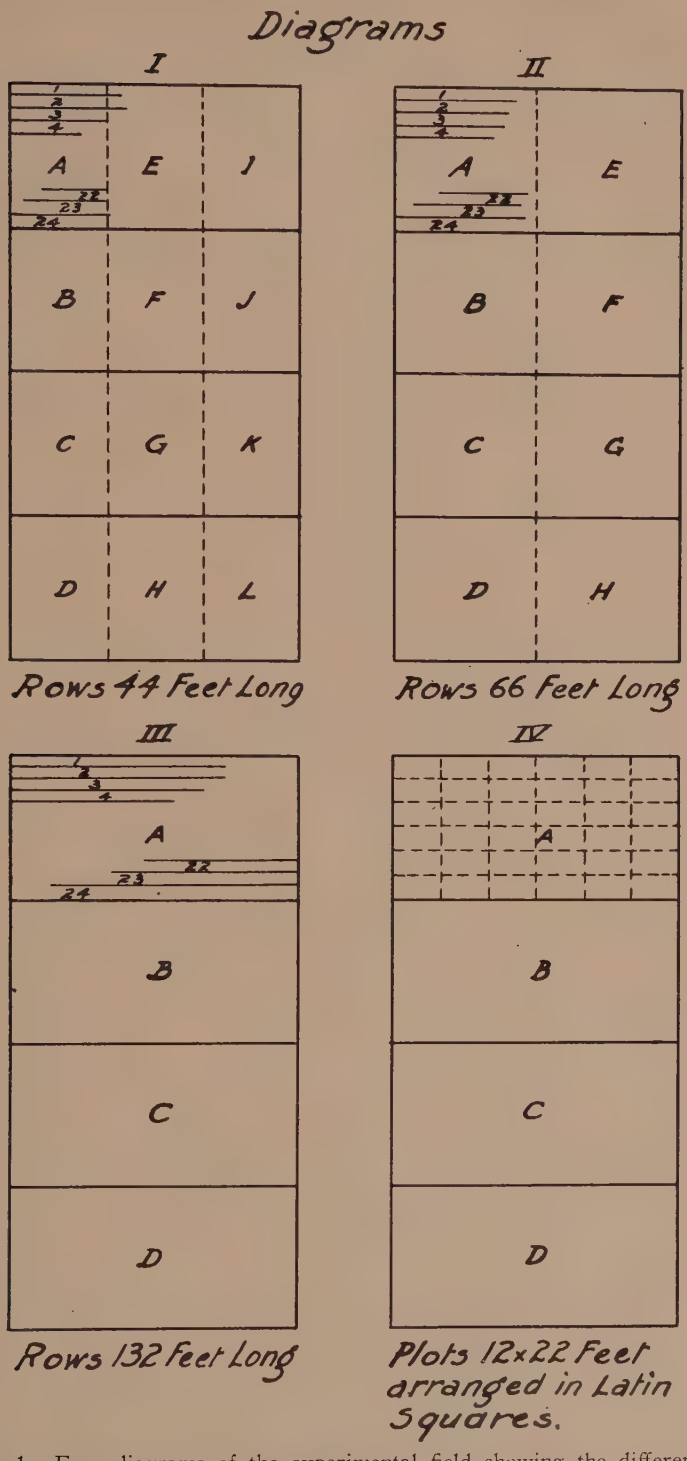

Figure 1. Four diagrams of the experimental field showing the different plot arrangements used in this study. Each lettered section contains twenty-four plots of the size indicated.

Analysis of the Data.

In discussing the results of this experiment reference will be made to Figure 1 which shows four diagrams of the experimental field, each representing a different plot size. Each lettered section contains 24 plots of the size indicated, which are numbered consecutively from 1 to 24. These may be regarded as 24 different varieties. The areas AB, CD, EF, etc., each include two replicates of the same 24 plots which occur in A. Similarly, the areas ABCD, EFGH, and IJKL each include four replicates. To obtain the coefficients of variability of two or four systematically distributed plots, the results from the replicates in two or four replication series are averaged and the coefficients calculated from these mean yields.

Diagram IV shows the plots arranged in a Latin Square. Each lettered section contains 36 plots consisting of four adjacent twenty-two foot rows. In a variety test there would be six varieties and six plots of each distributed at random except for the restriction that the same variety must not occur twice in the same row or column. The four sections therefore, would accommodate twenty-four varieties and these would occupy the same amount of land as twenty-four rows, one hundred and thirty-two feet long with four systematically distributed plots of each. Since all plots in this experiment are planted to the same variety, variation in yield due to varietal differences does not occur and therefore may be disregarded.

Table 1 gives the coefficients of variability with their probable errors for plots 44 feet in length. Single row plots are compared with two and four systematically distributed plots of the same size. In the case of single plots the coefficient of variability was obtained for the 24 plots in each section and these coefficients averaged for the whole field, the object being, as previously explained, to make allowance for the fact that smaller plots require smaller areas and for that reason are subject to less variability than larger plots which cover more land. The same procedure was followed where two and four systematically distributed plots were used. Approximately the same result as averaging the coefficients of variability would have been obtained by calculating the total variance and eliminating from this the variance of the mean yield of plots in each section of the field.

Table 2 gives the coefficients of variability for the 66-foot row plots. Because of the longer row there were not so many sections to include in each group average but the results are strictly comparable with the figures given in Table 1. Here again the value of replication is quite obvious. Comparisons between rows of different lengths will be taken up later when summaries of results are presented in tables 5 and 6.

Table 3 gives the results from plots 132 feet long. The coefficients of variability are somewhat smaller than the corresponding values in table 2 for the 66-foot plots, but the reduction is not large. The value of replication, however, as a means of reducing variability is as evident here as in the preceding cases where the plots are shorter.

Table 4 gives the coefficients of variability for plots arranged in a Latin Square. As previously explained, each Latin Square would accommodate six varieties, and four such areas, occupying the whole experimental

TABLE 1. *Coefficients of variability determined from the yields of row plots of potatoes 44 feet in length and with one, two and four systematically distributed plots.*

Section of field	Number of determinations	Number of systematically distributed plots	C. V.	Average C.V. of group	Mathematical expectation
A	24	1	7.55 ± .74		
B	24	1	8.61 ± .84		
C	24	1	8.53 ± .83		
D	24	1	8.84 ± .86		
E	24	1	6.84 ± .67	7.87	7.87
F	24	1	8.60 ± .84		
G	24	1	7.01 ± .68		
H	24	1	6.80 ± .66		
I	24	1	6.67 ± .65		
J	24	1	13.40 ± 1.30		
K	24	1	5.33 ± .52		
L	24	1	6.20 ± .60		
A & B	24	2	4.96 ± .48		
C & D	24	2	5.42 ± .53		
E & F	24	2	4.21 ± .41	4.70	5.56
G & H	24	2	3.96 ± .39		
I & J	24	2	6.21 ± .60		
K & L	24	2	3.45 ± .34		
A.B.C. & D	24	4	3.93 ± .38		
E.F.G. & H	24	4	3.30 ± .32	3.87	3.93
I.J.K. & L	24	4	4.39 ± .43		

TABLE 2. *Coefficient of variability determined from the yields of row plots of potatoes 66 feet in length with one, two and four systematically distributed plots.*

Section of field	Number of determinations	Number of systematically distributed plots	C. V.	Average C.V. of group	Mathematical expectation
A	24	1	5.49 ± .53		
B	24	1	8.73 ± .85		
C	24	1	6.71 ± .65		
D	24	1	7.65 ± .74	6.66	6.66
E	24	1	6.62 ± .64		
F	24	1	10.77 ± 1.05		
G	24	1	4.64 ± .45		
H	24	1	2.64 ± .26		
A & B	24	2	3.88 ± .38		
C & D	24	2	4.63 ± .45	4.28	4.71
E & F	24	2	4.83 ± .47		
G & H	24	2	3.78 ± .37		
A.B.C. & D	24	4	3.15 ± .31		
E.F.G. & H	24	4	4.19 ± .41	3.67	3.33

TABLE 3. *Coefficients of variability determined from the yields of row plots of potatoes 132 feet in length with one, two and four systematically distributed plots.*

Section of field	Number of determinations	Number of systematically distributed plots	C. V.	Average C.V. of group	Mathematical expectation
A	24	1	4.92 ± .48		
B	24	1	8.49 ± .83	6.03	6.03
C	24	1	5.02 ± .49		
D	24	1	5.70 ± .55		
A & B	24	2	3.40 ± .33	3.53	4.26
C & D	24	2	3.66 ± .36		
A.B.C. & D	24	4	2.99 ± .29	2.99	3.01

TABLE 4. *Coefficients of variability determined from the yields of potato plots arranged in Latin Squares.*

Section of field	Number of Determinations	Number of Systematically Distributed plots	C. V.	Average C.V. of group
A	36	6	2.2270 ± .26	
B	36	6	2.8266 ± .22	2.1735
C	36	6	1.7674 ± .21	
D	36	6	1.8730 ± .15	

field, would include 24 varieties. Approximately the same amount of land would be required as in the case of rows 132 feet long with four systematically distributed plots. These two methods of planting therefore are comparable in point of land and labour involved. The reduction in variability effected by planting in a Latin Square is worthy of note and will receive further consideration in the discussion which follows.

In order to facilitate a study of the value of replications as compared with increasing the length of row in experimental field plot tests with potatoes and also to bring out more clearly the comparative value of different methods of plot arrangement, the average values for the coefficients of variability presented in tables 1 to 4 have been brought together and summarized in table 5. The probable errors in per cent also have been included.

TABLE 5. *Coefficients of variability and probable errors in percent for plots of different sizes and different numbers of replications.*

	Number of systematically distributed plots. 1	2	4	6	
44 foot rows	7.87	4.70	3.87	Plots 12 x 22 feet arranged in Latin Squares	C.V.
	5.31	3.17	2.61		P.E.
66 foot rows	6.66	4.28	3.67		C.V.
	4.49	2.89	2.48		P.E.
132 foot rows	6.03	3.53	2.99	2.17	C.V.
	4.07	2.38	2.02	1.46	P.E.

It will be seen from table 5 that increasing the length of row was relatively ineffective in reducing variability in yield as compared with replication. For all three sizes of plots, four replicates were sufficient to reduce by one-half the coefficient of variability of a single plot test. The reduction in each case is almost exactly in agreement with mathematical expectation, i.e., directly as the square root of the number of replicates. On the other hand increasing the length of row from 44 to 132 feet decreased the coefficient of variability on the average about 25 per cent. In general it may be said that both increasing the length of row and increasing the number of replicates, in all cases reduced the variability materially but the latter was approximately twice as effective as the former.

It is interesting to compare the average coefficient of variability from the Latin Squares with that from the 132-foot rows with four systematically distributed plots. The reduction in variability of the former over the latter

arrangement of plots amounts to about 27 per cent. The area occupied with both methods of planting was the same. This very significant difference seems to indicate that the Latin Square method of planting or some similar arrangement with a random distribution of plots might be used with advantage, at least in some types of experiments where increase in accuracy is the primary consideration.

It is well known that the yield of potatoes varies greatly with soil differences. The measures of variability which have been obtained in most of the statistical studies with this crop have been abnormally high as compared with those commonly obtained in tests with cereals. Using two rod rows Krantz (*5*) found the average coefficient of variability to be 18.7 per cent for a single determination and 8.6 per cent for four systematically distributed plots. Westover (*8*) obtained a coefficient of variability of 36 for single 40-foot rows and 18 when four replicates were used. Kirk and Goulden (*3*) found the coefficient of variability to be 28.5 per cent for single rod row plots and 13.3 per cent for five systematically distributed plots of the same size. Results such as these seem to indicate that the factors which influence yield in potatoes are not easy to control, and that a reasonable degree of accuracy can only be secured by the best experimental technique.

It would appear that the potato crop tends to exhibit a greater response than many other crops to the heterogeneity of normal soils. That this is not necessarily so is evident from the magnitude of the coefficients of variability which are given in table 5. In this experiment single row plots 44 feet long gave a coefficient of only 7.87 and this was reduced to 3.87 when four replicates were used. By the use of 132-foot rows and the same number of replications, the coefficient of variability was further reduced to 2.99. The still smaller figure of 2.17 was obtained when the plots were arranged in Latin Squares. In the last instance the probable error is less than one and one-half per cent., an exceptionally good result with any crop under the most favourable conditions of experimentation.

TABLE 6. *Yield differences, in bushels per acre, which would be required in order to establish a significant difference between potato varieties in a crop averaging two hundred bushels per acre under the conditions of this experiment.*

	Number of systematically distributed plots.			
	1	2	4	6
44 foot plots	45.1	26.9	22.1	Plots 12 x 22 feet arranged in Latin Squares
66 foot plots	38.1	24.5	21.0	
132 foot plots	34.5	20.2	17.1	12.4

Table 6 gives the yield differences in bushels per acre which would be required in order to establish a significant difference between the yields of potato varieties in a crop averaging 200 bushels per acre under the same conditions as obtained in this experiment. Each figure represents three times the probable error in per cent, multiplied by $\sqrt{2}$ because we are dealing with the probable error of a difference, and this value taken twice

so as to make it correspond with a 200 bushel per acre yield. With a probable error of 5.31 per cent a difference in yield of 45 bushels would be required before one variety could be regarded as a significantly better yielder than the other. Similarly a probable error of 1.46 per cent as was obtained in the Latin Squares, would require a difference between varieties of 12.4 bushels to make reasonably sure that the difference in yield was significant.

The favourable result secured by arranging the plots in Latin Squares is due, of course, to the fact that this method of planting lends itself to the Variance method of analysis. The variance due to rows, columns, and varieties is subtracted from the total variance leaving only that due to random sampling. In this way the effect of correlation between plots is eliminated and the probable error is reduced accordingly.

When single rows are used and the usual systematic distribution adopted, as with the 44, 66 and 132-foot plots, there is frequently a high correlation between those which are adjacent or fairly close together. If the soil tends to vary uniformly in one direction lengthwise of the field, the correlation may increase the magnitude of the probable error of a difference for plots a considerable distance apart. This condition was encountered in the present experiment. The correlation coefficients (r) for 132-foot rows at different distances apart are given below. The third column shows the per cent reduction in the probable error of a difference (E_{x-y}) due to r.

Distance apart of rows	Value of r.	Percent reduction in E_{x-y} due to r.
Adjacent	.92±.015	71.71
4 apart	.85±.029	61.31
9 apart	.65±.065	40.88
14 apart	.53±.080	31.47
19 apart	.30±.104	16.27

If the correlation coefficients for all plots at the intervening distances were calculated and the complete formula for the probable error of a difference ($E_{x-y}=\sqrt{E_x^2+E_y^2-2rE_xE_y}$) used in comparing the yields of varieties at different distances apart, very marked reductions in the probable errors of differences would be effected. For adjacent plots and plots fairly close together, under the particular conditions of this experiment, there would be even some gain in accuracy over the Latin Square. However, in comparisons of plots further apart, the reduction in error would be much less. Besides, had the soil varied less uniformly in one direction, the probable errors of a difference might have been considerably larger. There remains also the practical objection of having to make so many laborious calculations in calculations in finding the value of r for plots located at different distances apart.

The results which have been presented correspond very closely with those obtained by other investigators. While the amount of reduction in variability due to increasing the size of plots and number of replicates is probably quite typical, it is to be expected that, with potatoes, considerably larger coefficients of variability would be obtained on most normal soils. The only warranted conclusion from this study and those of other investigators is that replication is much more effective in reducing the error due to soil

heterogeneity than increasing plot size, and that plenty of replications are necessary in order to reduce the variability to a practicable figure. The method of experimental technique adopted by each investigator must be determined by the variability of the soil, the degree of accuracy desired, and the facilities at his disposal.

ANALYSIS OF YIELD DATA FROM PLOTS ARRANGED IN A LATIN SQUARE.

The method and advantages of arranging plots in a Latin Square have been fully discussed by Fisher (*1*). By way of emphasizing the importance of better experimental technique he states that "when, by an improved method of arranging the plots, we can reduce the standard error to one-half, the value of the experiment is increased at least four fold; for only by repeating the experiment four times in its original form could the same accuracy have been obtained". In an article entitled "Mathematics and Agronomy", "Student" (*7*) has worked out a problem in detail for the purpose of illustrating how the necessary calculations should be made from Latin Square yield data.

An analysis of the yields of potatoes from plots in the Latin Square which occupied section A of the experimental field is given in table 7. It will be observed that the variability due to varietal differences is nil, because a single variety was used throughout the experiment.

TABLE 7. *Analysis of the yields of potatoes from plots in a Latin Square for section A of the experimental field showing the method by which the coefficient of variability was calculated.*

							Sums of rows
	94.9	108.7	116.4	115.5	108.1	110.4	654.0
	94.2	119.1	120.2	130.2	106.9	116.8	687.4
	112.0	113.7	123.5	130.5	128.2	108.4	716.3
	98.8	122.0	122.3	132.8	125.8	105.9	707.6
	100.5	109.0	117.8	126.3	107.5	101.6	662.7
	106.8	105.8	109.6	111.6	111.3	111.3	656.4
Sums of Columns	607.2	678.3	709.8	746.9	687.8	654.4	4084.4

General mean $= 4084.4 \div 36 = 113.4556$

Variance due to	Degrees of Freedom	Sum of Squares	Variance	Standard Deviation
Rows	5	610.6		
Columns	5	1896.6		
Remainder	25	957.6	38.3040	6.1890
Total	35	3464.8		

Standard deviation of the mean $= 6.1890 \div \sqrt{6} = 2.5266$

Coefficient of Variability $= \frac{2.5266 \times 100}{113.4556} = 2.2270 \pm .26$

The calculations from Latin Square yield data involve a considerable amount of work, even when a machine calculator is available. It was found, however, that the time required for carrying out the necessary mathematical computations could be very appreciably reduced by the use of special formulae adapted to machine calculation. These are simply extensions of Fisher's method of finding the sum of squares by taking the squares of the deviations of the totals from the mean total.

To obtain the sums of squares for rows, columns, varieties, and the total, the following formulae may be used:

$$\text{Sums of squares of rows} = \frac{\Sigma X_1^2}{n} - \frac{(\Sigma X)^2}{N}$$

$$\text{Sums of squares of columns} = \frac{\Sigma X_2^2}{n} - \frac{(\Sigma X)^2}{N}$$

$$\text{Sums of squares of varieties} = \frac{\Sigma X_3^2}{n} - \frac{(\Sigma X)^2}{N}$$

$$\text{Sums of squares of all plots (total)} = \Sigma X^2 - \frac{(\Sigma X)^2}{N}$$

In these formulae Σ stands for summation; X_1, X_2, X_3, the total yield of each row, column, and variety respectively; X, the individual plot yields; n, the number of rows, columns, or varieties; and N the total number of plots. Since the last term in each formula is the same, its value need be determined only once. Where this method of plot arrangement is employed extensively, the use of the machine method described above will be found to facilitate considerably the work of calculation.

Summary.

1. The present study consists of a statistical analysis of the results obtained in field plot experimental work with potatoes, the main object being to find the relative amount of error due to soil heterogeneity which may be expected from the use of different plot sizes, different numbers of replications and different methods of plot arrangement, including the Latin Square.

2. Tubers of a single variety of potatoes were planted in 132 foot rows and these were harvested in 22 foot units. The yields were then combined to give results for plots 44, 66 and 132 feet long. The mean yields of 1, 2 and 4 systematically distributed plots for each of the different sizes was obtained. Yields from four adjacent rows 22 feet long arranged at random in a Latin Square were studied also and the variability compared with the yield of row plots of different lengths with replicates systematically distributed.

3. Replication was found to be approximately twice as effective as increasing the length of row. Compared with a single plot test, four systematically distributed plots reduced the variability about fifty per cent, a result which agrees with mathematical expectation. Increasing the length of row from 44 to 132 feet, on the other hand, reduced the variability on the average about 25 per cent.

4. The variability of yields from plots distributed at random in a Latin Square was compared with the results obtained by the usual systematic distribution. Compared with 132 foot row plots and four replicates of each, the Latin Square method of planting gave a probable error which was 27 per cent lower, the same amount of land being required in each case.

5. A method adapted to machine calculation was suggested which has been found to facilitate the statistical analysis of the yields of plots arranged in a Latin Square.

LITERATURE CITED

1. Fisher, R. A. Statistical methods for research workers. Oliver and Boyd, London, Eng. 1928.
2. Hayes, H. K. and R. J. Garber. Breeding crop plants. McGraw-Hill Book Company, New York, 1927.
3. Kirk, L. E. and C. H. Goulden. Some statistical observations on a yield test of potato varieties. Sci. Agric. *6*: 89-97, 1925.
4. Krantz, F. A. A preliminary study of field plot technique in potato yield tests. Proc. Ninth Ann. Meeting of the Pot. Ass'n. of Amer. 1922, 42-44.
5. ———— Further studies in field plot technique in potato yield tests. Proc. Tenth Ann. Meeting of the Pot. Ass'n. of Amer. 1923, 174-179.
6. Meyers, C. H. and F. R. Perry. Analysis and interpretation of data obtained in comparative tests of potatoes. Jour. Amer. Soc. Agron. *15* : 239-253. 1923.
7. "Student." Mathematics and agronomy. Jour. Amer. Soc. Agron. *18:* 703-719. 1926.
8. Westover, K. C. The influence of plot size and replication on experimental error in field trials with potatoes. West Virginia Agr. Exp. Sta. Bul. 189, 1924.
9. Wilcox, A. N. A study of field plot technique with strawberries. Sci. Agric. *8*: 171-174, 1927.

ADMIXTURES AND OFF-TYPES IN MARQUIS WHEAT*

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Marquis is probably the most outstanding variety of wheat in the world. For years it has been the leading variety in Saskatchewan and at the present time occupies a far larger acreage than all other wheat varieties together. At the time of its introduction Marquis displaced other varieties rapidly which tended to keep it comparatively free from admixtures. Impurities however, have become increasingly noticeable in Marquis during recent years. Probably this has been due, first, to the action of the Canadian Seed Growers' Association in increasing the strictness of its regulations concerning the purity of registered Marquis wheat, and second, to an actual increase in impurities in Marquis stocks.

The advisability of investigating the purity of the existing strains and stocks of Marquis caused the writer (*2*) in 1925 to make an extensive study of fifteen strains of Marquis collected from various sources in Saskatchewan. Some of the strains were from single plant selections, some were from mass selections and others were from commercial stocks. Nine strains proved to be typical Marquis but six were not typical. Minor off-types were found in every strain but the proportion in the commercial stocks and non-typical strains averaged much higher than in the strains from single plant selections.

Newman (*4*) studied 167 samples of Marquis from commercial stocks including some unselected strains. He found that 61 per cent of the samples were not typical Marquis.

In 1928 Quisenberry, Clark and Bayles (*5*) investigated the prevalence of mixtures in 102 samples of Marquis grown in Central Montana. They found that 77.5 per cent of the sample showed white kernels. In addition there were other mixtures. These, with the plants from white seeds, averaged 9.4 per cent per sample.

DeLong (*1*) reported recently the results of an investigation of variation in Marquis where the plants were spaced different distances apart. He found that under extreme conditions there was a fairly wide range for various plant and spike characters.

MATERIALS AND METHODS

During the winter of 1925-26 the operators of all of the country elevators of the Saskatchewan Coöperative Elevator Company and a number of agricultural society secretaries were requested to furnish the writer with two samples of Marquis wheat from wagon lots just as they were delivered at elevators. In each case the name and post office address of the grower accompanied the seed. A total of 387 samples were received from 295 points‡. These samples were considered to be representative of the Marquis grown throughout the farmed area of Saskatchewan.

Approximately 100 seeds of each sample were sown in a nursery row in 1926. When the plants were mature, notes on off-types and admixtures were

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‡The appreciation of the writer is due to the elevator operators and agricultural society secretaries who supplied the samples.

taken. In 1927 progeny tests were made in all cases where the identity of a plant was doubtful. The admixtures and off-types were recorded in general categories based on field appearance as follows: awned plants with brown chaff, awned plants with white chaff, awnless plants with brown chaff, awnless plants with white chaff. Both tip-awned and awnless plants were classified as awnless. Off-types of minor character, that is, off-types not readily observable without close inspection, were not considered.

The Field Crops Branch of the Saskatchewan Department of Agriculture made an extensive collection of samples of wheat from drills in operation in fields all over the province in the spring of 1927. The Field Husbandry Department of the University of Saskatchewan coöperated in the investigation by making a progeny test of several hundred of the samples. The samples tested did not constitute a strictly random lot for they represented only 22 districts of the province and in several cases as many as eight samples were from the same district‡. Part of the samples were sown in 1927 and the remainder in 1928. The writer* examined the progenies from the samples and took notes on the kinds and amounts of admixtures and off-types, as was done with the elevator samples.

Results on the Amount of Impurity in Marquis Delivered at Country Elevators

Impurities were found in most of the 387 cultures grown. The summarized data are shown in table 1. Only 35 samples or 9.0 per cent were without obvious impurity. One hundred and twenty-five samples or 32.3 per cent contained only one of the four general kinds of impurities. Two kinds of impurities occurred in 105 or 27.1 per cent of the cultures, three kinds in 70 or 18.1 per cent and 17 samples or 4.4 per cent had all four types of impurity.

Table 1. *Summary of the data on the purity of 387 samples of Marquis wheat received in 1926 from 295 different points in Saskatchewan.*

Impurties	Number of samples	Percentage of samples
Kind of impurity found		
Bearded brown-chaff varieties and off-types	230	59.4
Beardless brown-chaffed varieties and off-types	119	30.7
Bearded white-chaffed varieties and off-types	143	37.0
Beardless white-chaffed varieties and off-types	176	45.5
Natural crosses of any of the above types	14	3.6
Number of different kinds of impurities found		
No obvious impurity	35	9.0
One of the four kinds	125	32.3
Two of the four kinds	105	27.1
Three of the four kinds	70	18.1
All of the four kinds	17	4.4
One or more kinds	352	91.0
Percentage of impurities found		
From 1 to 9 per cent	252	65.1
From 10 to 24 per cent	93	24.0
From 25 to 49 per cent	5	1.3
Over 49 per cent	2	.5

‡Only samples that were received by the Field Crops Branch prior to June 1, 1927, were forwarded to the University for test.

*Assisted by Messrs. W. Smith, W. J. Mather and G. N. Geiszler.

The amount of impurity may be summarized also according to the total percentage of impurities regardless of their type. There were 252 samples or 65.1 per cent that had 1 to 9 per cent impurities. Ninety-three cultures or 24 per cent contained 10 to 24 per cent of impurities. Only 7 samples were highly impure. Of these 5 or 1.3 per cent contained 25 to 49 per cent of impurity and 2 or .05 per cent had over 49 per cent.

Results on the Kind of Impurity in Marquis Delivered at Country Elevators

The impurities found in the Marquis samples consisted of identified varieties and various unidentified botanical types. The varieties found most frequently as admixtures were Ladoga, Preston, Stanley, Huron and Red Fife. Other varieties that occurred as mixtures were Ruby, Prelude, Early Red Fife, Red Bobs, Pioneer, Kota, Riga, Little Club, Kubanka, Mindum, Quality and Kitchener. The unidentified plants appeared for the most part to be segregates from natural crosses between Marquis and the varieties that occurred as admixtures. Fourteen of the Marquis cultures or 3.6 per cent contained unidentified plants that looked like first generation natural crosses. The progeny of each of these plants segregated in a manner to be expected from crosses between tip-awned and awned varieties.

All impurities were classified into four general groups on the basis of awning and chaff colour, whether they were identified varieties or unidentified botanical types. The prevalence of each of the four kinds of impurity is shown in table 1. Awned brown-chaffed impurities were found in 230 or 59.6 per cent of the samples. Awnless brown-chaffed impurities occurred in 119 or 30.7 per cent. In 143 or 37.0 per cent of the cultures there were awned white-chaffed plants. One hundred and seventy-six samples or 45.5 per cent contained awnless white-chaffed impurities.

The distribution of the four classes of impurities in the Marquis fields of the different parts of Saskatchewan was examined next in order to determine any possible localization of admixtures. Figure 1 shows for each of these kinds of impurity the distribution of the sources of the cultures in which the impurities were found. The principal awned brown-chaffed impurity was Ladoga. This variety was distributed to farmers in Saskatchewan between 1888 and 1893 by the Dominion of Canada Department of Agriculture as an early frost-escaping wheat. It displaced Red Fife to a certain extent at that time. Later Huron was introduced into the West for the same reason. Ladoga and Huron formed a large proportion of the identified impurities in the awned brown-chaffed group. The distribution of this class of impurity was very uniform over the province.

Among the awnless brown-chaffed impurities Stanley was very common. Stanley is an early variety from the cross Ladoga $\times$ Red Fife made about 1895 at the Central Experimental Farm, Ottawa. This variety was distributed in the West on account of its earliness. There is nothing however, in the distribution of the awned brown-chaffed class in Saskatchewan to indicate that the Marquis of one part of the province had more of this impurity than that of any other.

FIGURE 1. Distribution in Saskatchewan of different kinds of impurities in Marquis as ascertained from elevator samples.

Similarly the awned white-chaffed and the awnless white-chaffed impurities were evenly distributed over the farmed area of the province.

RESULTS FROM THE MARQUIS SAMPLES OBTAINED FROM SEED DRILLS BY THE SASKATCHEWAN DEPARTMENT OF AGRICULTURE

The same kinds of impurities were found in the seed drill samples as in the elevator samples, but the prevalence of the different impurities and the percentage purity of the samples were different as shown in table 2. Perhaps the most noticeable difference between the elevator samples and the seed drill samples was in the proportion with no obvious impurity. Only 9.0 per cent of the elevator samples showed no distinct impurity whereas 23.9 per cent of the seed drill samples appeared to be pure. With regard to percentage of impurities found, the seed drill material had a lower percentage of samples containing from 1 to 24 per cent of impurities but a larger percentage of samples with over 24 per cent of impurities than did the elevator samples. Over 24 per cent of impurities were found in 8.8 per cent of the seed drill samples but only 1.8 per cent of the elevator samples had that amount of impurity.

TABLE 2. *Summary of the data on the purity of 113 samples of Marquis wheat obtained in the spring of 1927 from seed drills in 32 districts of Saskatchewan by the Field Crops Branch of the Saskatchewan Department of Agriculture.*

Impurities	Number of sample	Percentage of samples
Kinds of impurities found		
Bearded brown-chaffed varieties and off-types	35	31.0
Beardless brown-chaffed varieties and off-types	26	23.0
Bearded white-chaffed varieties and off-types	39	34.5
Beardless white-chaffed varieties and off-types	57	50.4
Number of different kinds of impurities found		
No obvious impurity	27	23.9
One of the above four kinds	40	35.4
Two of the above four kinds	19	16.8
Three of the above four kinds	18	15.9
All of the above four kinds	10	8.9
One or more kinds	87	77.0
Percentage of impurities found		
From 1% to 9%	53	46.9
From 10% to 24%	23	20.4
From 25% to 49%	6	5.3
Over 49%	4	3.5

DISCUSSION

Impurity in a wheat variety is not desirable, chiefly because it tends to lower the market value of the grain. The Canadian Seed Growers' Association, in its endeavor to promote the growing of better varieties and crops, bars from registration any crop containing more than .01 per cent of obvious impurities such as awned or brown-chaffed plants in Marquis.

Most agricultural people of the western plains of Canada are familiar with the popular complaint that Marquis frequently "throws" plants with awned or with brown-chaffed spikes. The claim is made that these plants appear suddenly in fields of Marquis that in preceding years appeared to be free from such foreign types. It is assumed that Marquis is not entirely "fixed" in type and produces an occasional plant having some character of Hard Red Calcutta, one of the parent varieties of the original cross. The present study has shown the nature, amount and distribution of various impurities that occur in Marquis and evidence has been given which indicates the origin of most of these impurities.

Impurities in a variety may be due to several causes, viz:

(a) Segregation resulting from the original cross.
(b) Mutation.
(c) Mechanical mixing.
(d) Segregation resulting from natural crosses between the variety and other varieties.

Segregation resulting from the original cross is a common cause of variation in hybrid varieties that are not fully fixed for uniformity of characters. According to the laws of inheritance, a hybrid variety from a cross between homozygous self-fertilized varieties would, without the aid of selection by man, become about 97.37 per cent pure-breeding for easily observable morphological characters during the first ten generations following the cross, if no further crossing took place after the original cross. Similarly a hybrid variety twenty generations from the original cross would

have become about 99.98 per cent pure-breeding for these characters. Marquis has been in existence more than twenty years and was subjected to a considerable amount of selection to rid it of undesirable characters during the first several generations. When distributed in 1909 Marquis was reasonably uniform for lack of awns and chaff colour. There is little likelihood of bearded or otherwise off-type plants appearing nowadays in this variety as segregation products of the original cross between Red Fife and Hard Red Calcutta.

Mutation in wheat has been reported rarely although dozens of investigators have carried on detailed inheritance studies where mutations of any importance should have been observed readily. It is improbable that mutation has been an appreciable disturbing factor in the maintainance of Marquis purity.

Mechanical mixing, on the other hand, has undoubtedly played a large part in the pollution of Marquis fields and seed stocks. The data presented in this paper reveal a surprising amount of impurity in representative Marquis cultures grown in Saskatchewan. Ninety-one per cent of the samples from country elevators showed obvious impurities; 25.8 per cent of the samples contained over 9 per cent of impurities. For the most part the mixtures found were of the varieties Ladoga, Stanley, Huron and Red Fife all of which were grown in Saskatchewan at the time Marquis was introduced and were displaced largely by that variety. It is not difficult to imagine how the mixing occurred. Where more than one variety is grown or handled mixing results from incomplete cleaning of sacks, bins, fanning mills, drills, cultural implements, threshing machines, etc., between the handling of one variety and another.

Segregation resulting from natural crossing between Marquis and other varieties probably has been responsible for the numerous impurities that cannot be classified as named varieties. Natural crossing in wheat occurs fairly frequently in dry climates. Hayes and Garber (*3*) reported about 2 per cent in Minnesota. Extensive studies made by the writer at Saskatoon during the past five years have shown that natural crossing between varieties of wheat in adjacent small plots varies from a negligible amount to as high as 5 per cent, depending upon the varieties used and the weather. In one case a select stock of Marquis was grown in a small plot beside a small plot of Kubanka durum wheat, the latter being sown two weeks later than the Marquis. The next year there were so many F_1 durum $\times$ common hybrids in the Marquis that it had to be discarded.

In a field of Marquis admixture plants of other varieties are entirely surrounded by Marquis plants. Under such ideal circumstances it is almost inevitable that frequent natural crossing takes place. The more admixtures there are in the field the greater will be the opportunity for natural crossing. Also where Marquis is grown within a few feet of another variety it is likely that a considerable amount of natural crossing occurs.

As a result of natural crossing between Marquis and another variety plants having various combinations of the contrasting characters of the two varieties appear in the segregating generations. Some of these resemble Marquis in certain respects and the other variety in other respects. As the years pass, these natural crosses become more and more fixed in their type,

according to the Mendelian principles of inheritance, until they become as stable as plants of the original parent varieties. At any particular time one would expect to find in a Marquis field containing mixtures of other varieties a varied assortment of off-types, that more or less resembled Marquis in some characters. Some of these off-types would break up or segregate upon being given a progeny test and others would breed true.

In the present study natural crosses resembling the F_1 generation of crosses between Marquis and bearded varieties were found in 14 of the elevator cultures. (No notes were taken on natural crosses in the seed drill samples.) Each of these, when given a progeny test, segregated like a typical F_2. This is direct evidence that natural crossing takes place in impure Marquis. The 14 plants selected as obvious natural crosses probably represent only a small proportion of the new natural crosses that were present in the cultures grown, for it is evident that many of the new natural crosses would not be easily distinguishable from segregates of natural crosses that had occurred in previous years.

The results from the seed drill survey material collected by the Department of Agriculture of Saskatchewan corresponded in general with those from the elevator samples. Differences between the two sets of samples with respect to the kinds and amounts of impurities probably are due largely to the fact that the elevator samples were obtained from 287 different points in Saskatchewan, whereas the seed drill samples that were tested came from only 22 different districts and were not as thoroughly representative of the whole province. This explanation does not answer, however, for the noticeable differences in purity and in the percentage of highly impure samples.

The proportion of apparently pure elevator samples was much lower than the proportion of seed drill samples showing no obvious impurity. This indicates that purer seed is sown than is marketed at the elevators. Such a finding is to be expected. Frequently a farmer sows pure seed but the crop becomes contaminated by other varieties through volunteer grain, through mixing due to seed of other varieties being brought in on the racks and separator of a custom thresherman, and through other common agencies.

The reason why a larger proportion of seed drill samples than elevator samples was highly impure may be sought in the manner in which the samples were collected. The seed drill samples were taken irrespective of variety; consequently any badly mixed wheat would be taken just the same as Marquis. In the elevator collection of samples only Marquis was asked for. The elevator operator took samples from the first load or two loads that appeared to be Marquis and which the grower called Marquis. Loads that were less than three-quarters Marquis would probably under such circumstances not be sampled.

The present study has shown the condition of existing representative Marquis stocks in Saskatchewan with respect to purity. Of the four possible causes for impurity in Marquis two are important: mechanical mixture and natural crossing. There are various measures that can be taken to ameliorate the condition. Perhaps the most important ones are: (a) the use of pure seed, (b) the use of only one variety on a farm when possible, (c) sowing different varieties of wheat several rods apart, the farther the better, and (d) cleaning all equipment thoroughly before handling a different variety.

SUMMARY.

1. From 295 representative points in Saskatchewan 387 samples of Marquis wheat were obtained from country elevators. A plot of each culture was grown and the kind and amount of impurity was recorded. Progeny tests were made where necessary.

2. Only 9.0 per cent of the elevator samples were without obvious impurity; 32.3 per cent contained one of the four general types of impurity (awned plants with brown chaff, awned plants with white chaff, awnless plants with brown chaff, awnless plants with white chaff); 27.1 per cent contained two kinds of impurities; 18.1 per cent showed three impurity types; 4.4 per cent had all four impurity types.

3. Percentage of impurity varied from zero to over 50 per cent; 65.1 per cent of the samples contained 1 to 9 per cent of impurities; 24 per cent contained 10 to 24 per cent of impurities; 1.3 per cent had 25 to 49 per cent; 0.5 per cent were over 49 per cent impure.

4. The impurities consisted of identified varieties and various unidentified botanical types. The varieties found most frequently were Ladoga, Preston, Stanley, Huron and Red Fife. The unidentified plants appeared for the most part to be segregates from natural crosses between Marquis and the varieties that occurred as admixtures. New natural crosses were found in fourteen samples.

5. The four general types of impurity occurred in the following relative proportions: awned brown-chaffed impurities in 59.6 per cent of the samples; awned white-chaffed in 30.7 per cent; awnless brown-chaffed in 37.0 per cent; awnless white-chaffed in 45.5 per cent. None of these types appeared to be more prevalent in one part of the province than another.

6. Progeny tests were made of 113 samples of Marquis that were obtained by the Field Crops Branch of the Saskatchewan Department of Agriculture from 22 districts of the province in the course of a seed drill survey.

7. The same kinds of impurities were found in the seed drill samples as in the elevator samples and in general their prevalence was about the same. A far larger percentage of the seed drill samples was pure than of the elevator samples, indicating that purer wheat is sown than is marketed at elevators.

8. Mechanical mixing and natural crossing appear to be responsible for practically all of the impurities in Marquis. It would seem to be highly desirable (a) that fewer varieties be grown, (b) that all seed and crops handling equipment be cleaned well between its use on one variety and its use on another, and (c) that one wheat variety be sown at least several rods from another.

LITERATURE CITED

1. DELONG, G. E. A study of variations of Marquis wheat in relation to different spacing of plants. Sci. Agric. *9*: 282-300. 1929.
2. HARRINGTON, J. B. A comparative study of strains of Marquis wheat. Sci. Agric. *8*: 77-104, 1927.
3. HAYES, H. K., and GARBER, R. J. Breeding crop plants. McGraw Hill Book Co., New York. 438 pp. 1927.
4. NEWMAN, L. H. Classification of Canadian spring wheat varieties. Plant Breeders' Series No. 1. Can. Seed Growers Assoc. Jan. 1926.
5. QUISENBERRY, K. S., CLARK, J. A., BAYLES, B. B. The prevalence of mixtures in Marquis wheat grown in Central Montana in 1926. Jour. Amer. Soc. Agron. *20*: 1055-1063. 1928.

FREQUENCY OF NATURAL CROSSING AND ITS ASSOCIATION WITH SELF-STERILITY IN PURE LINES OF MARQUILLO WHEAT.*

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Introduction

The frequency of the occurrence of natural crossing in wheat has an important bearing on plant breeding procedure and variety testing with this crop. The usual custom is to grow different varieties and strains in adjacent plots and to consider the effect of natural hyridization to be practically negligible over a period of two or three years. This custom has arisen through a common concensus of opinion that wheat is a naturally self-fertilized crop and the majority of reports on the frequency of natural crossing lend support to this view. At the Minnesota Experiment Station, Hayes (*3*) and Hayes and Garber (*4*) report 2 to 3 per cent of natural crossing over a considerable period of years. This seems to have been the first experimental evidence of an appreciable amount of natural crossing in wheat and demonstrated the importance of frequent roguing and reselection from variety plots, and of taking care in order to minimize the possibility of natural hybrids occurring in the pursuance of genetic studies. Also in the two interspecies crosses *Triticum dicoccum* X *T. vulgare* and *T. vulgare* X *T. durum*, Hayes, Parker and Kurtzweil (*5*) report 18.5 per cent of the F_3 were from natural crossing occurring in the F_2. In such interspecies crosses we have a very apparent degree of self-sterility and crossing with other varieties grown in nearby plots is to be expected.

The most striking results on the frequency of natural crossing are those reported by Leighty and Taylor (*6*). Their observations covered a period of ten years, 1917 to 1926 inclusive. The most frequent crossing occurred in 1917, 1920, and 1924. In the variety Fulcaster 34 per cent of crossing occurred in 1917 and the two varieties Nebraska 28 and Kanred gave a consistently high percentage of natural crosses as compared to other varieties. It was shown also that a much higher percentage of crossing occurred in the secondary tillers than in the primary tillers. In general Leighty and Taylor believed that the frequency of crossing was associated with the suitability of a variety for its environment. Unsuitable varieties such as Kanred and Nebraska 28 at Arlington Farm, Va., were therefore particularly prone to natural crossing. This and the difference between secondary and primary tillers lead to the view that an appreciable degree of self-sterility in wheat exists and that this is reflected in the frequency of natural crossing.

The experiments reported in this paper were initiated in order to obtain some measure of the extent with which a rust resistant variety might cross with a susceptible variety, and consequently deteriorate in value. Marquillo was selected as the most convenient variety for making the tests. It is highly resistant in the seedling stage to physiologic form 21 of *Puccinia graminis*

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tritici, Erikss. and Henn., to which a number of standard Canadian varieties such as Marquis, Preston, Huron, and Garnet are susceptible; and in crosses with these varieties susceptibility is dominant. F_1 seedlings resulting from crosses of Marquillo with either of the above varieties are therefore very easily detected by their reaction to form 21. This forms the basis for a novel and rapid method of determining the amount of natural crossing.

Materials and Experimental Procedure.

In general, the procedure of the experiment consisted of growing pure lines of Marquillo adjacent to rows of Huron and Preston and covering one or two heads on a number of Marquillo plants in each line in order to prevent cross pollination. In the seedlings from these plants the number of susceptibles obtained from the heads which were not bagged gave the percentage of natural crosses. The seed from the bagged heads served as a check on the technique of the experiment.

The Marquillo pure lines used in this study came from 110 head selections made in 1925 from the variety plots of Marquillo. The seed had been obtained from the Brandon Experimental Farm having come originally from the Minnesota Experiment Station where the variety Marquillo was produced. These 110 head selections were grown in 1926, each in a five-foot row in which the plants were spaced. Notes were taken on each line with regard to rust reaction and morphologic characters. In 69 lines all of the plants were resistant to rust and morphologically pure. In 25 of the lines approximately 1.5 per cent of the plants on the average were susceptible to rust. In 16 lines approximately 25 per cent of the plants were susceptible.

For the natural crossing experiment in 1927, ten single plant selections were made from five of the lines grown in 1926 which were practically pure. The history of these lines and their behaviour in 1926 is shown in table 1 below.

Table 1. *History of ten pure lines of Marquillo used in the natural crossing study in 1927.*

Nursery Stock No. Selections Made in 1926	Nursery Stock No. Selections Made in 1925	Behaviour in 1926. No. of Plants		
		Res.	Semi-Res.	Susc.
S-25-55, -67, -68	S-25-63	56	0	0
-86, -90	S-25-64	54	0	0
-87	S-25-60	51	0	0
-121, -130	S-25-68	65	1	0
-148, -149	S-25-70	21	2	0

In 1927 four five-foot rows of each line, in which the plants were spaced, were grown adjacent to rows of Huron and Preston. In each line a single head was bagged on each of 20 plants. The bags were placed on the heads just before the heads emerged from the sheathes. For the study in 1928 only 5 lines were used and 2 heads on each 40 plants in a line were covered with bags. The seed for the 1928 material was extra seed from plants bagged

in 1927. In bagging the heads an attempt was made not to always select for this purpose the primary heads. The results obtained by Leighty and Taylor were not known at this time but it seemed desirable not to make the natural crossing test on heads that were not decidedly secondary tillers.

At harvest the heads covered and uncovered from each plant were kept together and at threshing the seed envelopes were labelled with the plant number and S for selfed or covered, or O for open or uncovered. For the rust test most of the seed from the covered heads was used and an equal number from each plant from uncovered heads. Both sets of seedlings were inoculated with form 21 at the same time and readings of rust reactions were taken without knowledge as to the nature of the seedlings i.e., whether they came from covered or uncovered heads.

Results and Discussion

The rust tests gave strikingly clear differentiations between resistant and susceptible plants. The susceptible plants were so outstanding that the number in each pot could be counted at a distance of 5 or 10 feet. Text figure 1 shows the reactions fairly well. As a further check, F_1 seedlings from crosses in which Marquillo was pollinated with Huron and Preston were tested. These give reactions exactly similar to the susceptible seedlings from uncovered heads of Marquillo in the natural crossing experiment. It was observed also that F_1 seedlings of Marquillo $\times$ Preston gave rust pustules surrounded by a deep purple area while F_1 seedlings from Marquillo $\times$ Huron gave rust pustules surrounded by the usual yellowish chlorotic area. It was possible therefore, after this was discovered, to differentiate between the Marquillo $\times$ Huron and the Marquillo $\times$ Preston natural crosses in the seedling stage.

Figure 1. Right—normal reaction of Marquillo to form 21. Left—reaction F_1 seedlings of Marquillo $\times$ Huron and Marquillo $\times$ Preston.

TABLE 2. *Numbers by lines of resistant and susceptible seedlings from covered and uncovered heads of Marquillo plants grown in 1927.*

Line No.	Covered Heads		Uncovered Heads	
	Res.	Susc.	Res.	Susc.
S-26-130	401	0	330	3
S-26- 55	418	1	337	2
S-26- 86	355	0	289	1
S-26-121	411	2	346	2
S-26-149	304	1	269	2
S-26- 90	449	1	352	0
S-26-148	359	0	296	3
S-26- 68	462	2	381	1
S-26- 87	437	2	356	2
S-26- 67	365	0	303	3
Totals	3961	9	3259	19

Per cent susceptibles in uncovered = 0.58 per cent.

TABLE 3. *Numbers by lines of resistant, semi-resistant, and susceptible seedlings from covered and uncovered heads of Marquillo plants grown in 1928.*

Line No.	Covered Heads				Uncovered Heads					% Susc.
	R	SR	Sn	O	R	SR	Sn	Sp	O	
S-26-67	570	1	2	389	598	4	49	10	297	8.98
-68	805	0	2	116	755	0	89	7	83	11.28
-148	601	3	2	137	530	2	56	30	137	13.96
-87	671	2	3	108	610	1	83	9	100	13.10
-130	323	5	1	169	286	6	84	42	139	30.58
Totals	2970	11	10	919	2779	13	361	98	756	16.51=Av.

The seedling test results are given in tables 2 and 3. In 1927 the seedlings were divided into two classes only, resistant and susceptible. A few plants in each line failed to give any rust reaction but these were so rare that they were not counted. In 1928 the inoculations were not quite so successful and the plants giving no reaction were more numerous. Consequently the exact number of such plants was recorded and they are given in table 3 under the column headed O. Note also that the susceptibles are classified as S_n and S_p. The former are presumably crosses with Huron as the pustules were surrounded by the normal yellowish area. The latter are plants giving pustules surrounded by a purple area and presumably are crosses with Preston. Another class of seedlings of rare occurrence were designated as semi-resistant and are given under the column headed SR. These seemed to be about equally frequent in the seedlings from covered and uncovered heads and were disregarded in estimating the percentage of natural crossing. Also in estimating the percentages the plants giving no reaction were disregarded, as it seemed reasonable to assume that susceptible plants were just as likely to escape infection as resistant plants. In reading the reactions an occasional plant gave some difficulty but if there was any doubt it was classed as resistant or semi-resistant. Thus every effort was made not to over-estimate the percentage of susceptible plants.

In the winter of 1927-28 when the first group of material was being studied in the greenhouse, the susceptible plants were transplanted and grown to maturity and were compared with F_1 plants of crosses between Huron and Marquillo and Preston and Marquillo. Most of those from the uncovered group were typical F_1 plants and some from the covered group were

also fairly typical first generation hybrids. A random sample of the susceptibles obtained from the 1928 material is being grown at present, but the plants are not yet far enough towards maturity to enable us to study the types.

The two sets of results, those for the 1927 and the 1928 rust readings show a very striking contrast. In 1927 the average percentage of susceptible seedlings was only 0.58 per cent while in 1928 it varied from 8.98 per cent in line S-26-67 to 30.58 per cent in line S-26-130. As to the significance of these results we merely have to compare them with the results obtained from the covered heads. The susceptibles obtained from the covered heads are probably also due to accidental crossing but this point is not definitely known as present. In 1927 the susceptibles obtained from the uncovered heads differed significantly from those obtained from the covered heads. The results are: uncovered, 3259 resistant and 19 susceptible; covered, 3961 resistant and 9 susceptible. Comparing these results by calculating χ^2 we get $\chi^2 = 5.81$ and P = about .02. The difference in 1928 between the proportion of susceptibles from uncovered and covered heads is much more striking and statistical determinations of significance are unnecessary. These results together with comparisons of F_1 plants with plants grown to maturity from susceptible seedlings, demonstrate that the percentage of susceptible seedlings may be used to determine the percentage of natural crossing.

The 1927 test was not quite satisfactory from the standpoint of getting the maximum amount of natural crossing as the Huron and Preston rows were sown at the same time as the Marquillo rows and the latter headed a few days earlier. In 1928 this was corrected by sowing the Huron and Preston earlier than the Marquillo.

This, of course, may not account for the very wide difference between the results for the two years. It is quite possible that seasonal conditions may have a marked effect upon the frequency of natural crossing and the 1928 season may have been particularly favorable.

One of the most interesting features noted in this study is brought out by a comparison of lines in the 1928 material, of the percentage of susceptible seedlings and the average number of seeds set on the covered heads. If the latter may be taken as an approximate measure of the self-fertility of the lines and the former of the amount of natural crossing, there appears to be an association between these two characteristics of the lines. This relation is shown graphically in figure 2 and the correlation between the five pairs of values also given on the graph is -.799. Fisher (*1*) gives a table showing the values of the correlation coefficient for different degrees of freedom and different levels of significance. With only five pairs of values this coefficient should be -.811 in order to be significant. It does not quite meet this requirement but it is so close to being a significant value that it cannot be disregarded. This is emphasized further by the results given in table 4. This table gives the distribution by lines of the numbers of seeds in two covered heads of single plants and the calculations of the significance of the differences between the mean values for the lines. Applying Dr. Fisher's analysis of variance we find these differences to be quite significant. If there are real differences in self-fertility we can logically

Line No.	Number of Seed*																						Total	Mean†
	5	8	11	14	17	20	23	26	29	32	35	38	41	44	47	50	53	56	59	62	65	68	71		
S-26-130	1	1	8	9	5	6	2	2	2	1	1													38	17.41
- 87		1	5	4	4	4	7	3	4	3	2	2	1											40	22.38
-148		1	3	4	2	3	5	2	3	4	3	4	2	2										38	26.97
- 68			2	2	1	5	5	5	3	1	5	2	3	3	1	1	1							40	27.70
- 67				1	1	1	2	2	4	3	6	5	4	4	4	1		2					1	41	37.46
Totals	1	3	18	20	13	19	21	14	16	12	17	13	10	9	5	2	1	2					1	197	

Analysis of Variance

	Sums of Squares	Degrees of Freedom	Variance	Square Root Variance	Nat. Log.
Total	3006.9883	196			
Within Classes	2020.1923	192	10.5218	3.2437	1.1767
Between Classes	986.7960	4	246.5481	15.7018	2.7538
					1.5771 = Z

$$Z/\sigma_Z = 1.5771/.3572 = 4.42$$

*In calculations class interval of 3 is replaced by class interval of unity.
†Means calculated from single values and not from distributions given here.

TABLE 5. *Distribution by lines of percentages of susceptible seedlings from Marquillo plants grown in 1928, and calculation of the significance of the differences between the mean values.*

Line No.	Percentage Susceptible Seedlings*																				N	Mean†
	0-5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100		
S-26-67	17	8	7	1	4	1	1	1						1							41	8.98
-68	16	7	6	3	4	1	2	1													40	11.28
-87	12	8	5	5	5	4	1														40	13.10
-148	12	7	6	4	4	2	2	1													38	13.96
-130	4	3	3	2	7	4		5		2	2		1	1	2	1				1	38	30.58
Totals	61	33	27	15	24	12	6	8		2	2		1	2	2	1				1	197	

Analysis of Variance

	Sums of Squares	Degrees of Freedom	Variance	Square Root Variance	Nat. Log.
Total	2028.0165	196	7.9755	2.7920	1.0268
Within Classes	1531.2913	192	124.1813	11.1437	2.4107
Between Classes	496.7252	4			
					1.3839 = Z

$$Z/\sigma_Z = 1.3839/.3572 = 3.87$$

*Class interval of 5 is replaced by unity in calculations.
†Means calculated from single values and not from distributions given here.

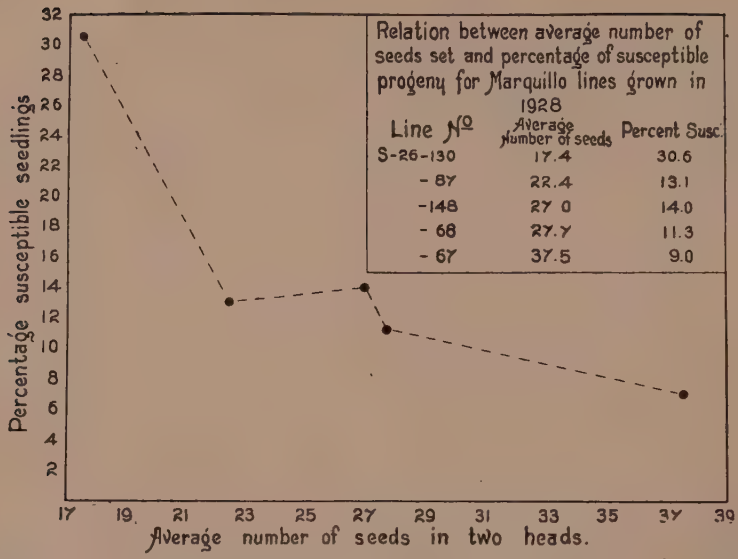
Relation between average number of seeds set and percentage of susceptible progeny for Marquillo lines grown in 1928
Line No. | Average number of seeds | Percent Susc.
S-26-130 | 17.4 | 30.6
- 87 | 22.4 | 13.1
-148 | 27 0 | 14.0
- 68 | 27.7 | 11.3
- 67 | 37.5 | 9.0
Percentage susceptible seedlings
32 30 28 26 24 22 20 18 16 14 12 10 8 6 4 2
17 19 21 23 25 27 29 31 33 35 37 39
Average number of seeds in two heads.

FIGURE 2. Relation between average number of seeds set and percentage of susceptible progeny for Marquillo lines grown in 1928.

expect corresponding differences in the tendency towards natural crossing. Further support to this view is given by the results and calculations in table 5. The mean values for natural crossing are also significantly different and the correlation coefficient of –.799 shows that in general these mean values are negatively associated with the means for self-fertility.

The line S-26-130 shows a particularly high percentage of natural crossing in 1928 and a correspondingly low self-fertility. The most fertile line S-26-27 produced an average of 37.46 seeds on two covered heads while line S-26-130 produced only 17.41 seeds on two heads. This is an indication of self-sterility in line 130 amounting to approximately 50 per cent. In the taking of data on self-fertility it is of course, desirable to make actual counts on the percentage of infertile flowers but in this study the importance of self-fertility of the lines did not appeal to the writers until the very high percentages of natural crossing had been observed, and the number of seeds set were the only data then available. It is possible that such lines as S-26-130 may be lacking in vigour and this would probably result in its producing less than the average number of seeds per head even with high fertility. However, it seems very doubtful if such a condition would account for the difference observed, for example, between lines S-26-67 and S-26-130.

Lines S-26-67 and S-26-68, as shown in table 1 came from the same line S-25-63 and it is interesting to note that they gave very similar results for natural crossing, while the results for differences in self-fertility are not highly significant.

In stating the results for natural crossing it was thought best to express these as the percentage of plants definitely known to have arisen from pollinations by other varieties: Griffee and Hayes (2) have pointed out that it is reasonable to double this figure in order to obtain a figure for the actual percentage of natural crossing between plants whether of the same or of

another variety. However, if there are indications of self-sterility it is obvious that this procedure is not justifiable and this is increasingly so as self-sterility increases. In line S-26-130, ten plants gave 50 or more per cent of susceptible seedlings and it would not be logical here to double the figure as we cannot have more than 100 per cent of natural crossing. It must be recognized of course t,hat the percentage of susceptible plants is probably lower than the actual percentage of natural crossing between plants.

Discussion

The importance of the high degree of natural crossing obtained in this experiment cannot be definitely interpreted as yet. In the first place it may be a peculiar characteristic of the variety Marquillo or of the particular strains selected for the study and in the second place it may be a seasonal effect and consequently may have affected all varieties in an equal manner. At the time the selections were made from Marquillo a number of plants very susceptible to stem rust were observed in the parent stock and this was partly the reason for making selections. Since the variety was of recent origin at the Minnesota Experiment Station it seemed possible that the susceptible plants might be due to segregation as at this time the stock was being sent out to different Experiment Stations with the definite understanding that it was not guaranteed to be pure. The differences between the five strains used in the natural crossing experiment with respect to fertility and percentage of natural crossing however, are significant. It should be noted that with respect to natural crossing, strain S-26-130 is quite different to the others. It may be that this strain is exceptional and that the other four strains showing such great differences either for natural crossing or self-fertility are fairly typical of the variety. At any rate the results indicate that new selections or hybrid strains should be tested for their tendency towards natural crossing. If self-fertility can be taken as a fair measure of the tendency towards natural crossing a simple test of the self-fertility of new strains in comparison with older and recognizably stable varieties may be quite sufficient.

As previously pointed out Leighty and Taylor (*6*) concluded that there were significant differences between varieties with regard to their tendency towards crossing and also that seasonal effects are quite noticeable. They mention also the presence of black chaff caused by *Bacterium transluscens var. undulosum,* Smith, Jones, and Reddy, which they state may have had some influence on the self-fertility. In unpublished data, Goulden and Neatby, a study is reported of the effect of black chaff upon yield in a group of Marquillo lines grown in 1928. Black chaff was found to be negatively correlated with yield and in the light of the present study it appears that the reduction in yield may have resulted partly from infertility brought about by the black chaff disease. The natural crossing experiment was located upon drier soil than the other experiment and the effect of the disease was scarcely noticeable; but it may still have been present in sufficient quantity to influence the general vigour and fertility of the plants.

Note

Dr. H. K. Hayes of the Minnesota Experiment Station has been kind enough to read the manuscript of this paper and make some comment on the

behaviour of the variety Marquillo under Minnesota conditions. He points out that the somewhat greater variability of Marquillo as compared to other varieties has been recognized for some years and that much of this has been attributed to natural crossing.

LITERATURE CITED

1. Fisher, R. A. "Statistical Methods for Research Workers." Oliver and Boyd, Edinburgh.
2. Griffee, F. and H. K. Hayes. Natural crossing in oats. Jour. Amer. Soc. Agron. *17*: 545-549, 1926.
3. Hayes, H. K. Natural crossing in wheat. Jour. Hered. *9*:326-330, 1918.
4. Hayes, H. K., and R. J. Garber. Breeding crop plants. McGraw Hill Book Co., New York.
5. Hayes, H. K., J. H. Parker, and C. Kurtzweil. Genetics of rust resistance in crosses of varieties of *Triticum vulgare* with varieties of *T. durum* and *T. dicoccum*. Jour. Agric. Res. *19*: 523-542, 1920.
6. Leighty, C. E. and J. W. Taylor. Studies in natural hybridization of wheat. Jour. Agr. Res. *35*: 865-887, 1927.

from Montreal on June 22nd. A meeting of those in eastern Canada who

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BOOK REVIEW

Agricultural Education in the United States by Whitney H. Shepardson. (The Macmillan Company, New York, N.Y.).

Paradoxically, the viewpoint of the unprofessional and uninitiated has become to be quite highly regarded in our days of experts and specialists, particularly when questions arise regarding long established and tradition-bound institutions and practices. That this should be so is in itself a great tribute to the expert, for very often it is he who calls on the layman for fresh and untrammeled views after having become hopelessly entangled in such a maze of professional detail—knowledge that an unbiased outlook becomes impossible.

The present book is an example of this trend. Dr. W. Rose, of the General Education Board, called on the author to make a survey of the land grant colleges, their functions, and to make recommendations as to how their usefulness could be widened. Mr. Shepardson, in his own words, knew very little about education and nothing about agriculture, but he approached his task with a sympathetic outlook on both, got the necessary professional advice interesting both in presentation and subject matter. The Canadian reader will find a great deal of information in these pages, and the style is so attractive that the volume is to be recommended for a Sunday afternoon's reading. The author, who was in business before beginning this survey and who went back to business after completing his report, has made a worth-while contribution to the problem of agricultural education in the United States.

F.T.W.

THE DEVELOPMENT OF SECONDARY SEMINAL ROOTS IN CORN SEEDLINGS*

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[Received for publication April 3, 1929].

The seminal root system of a grass plant constitutes the medium by which the seedling absorbs moisture and plant nutrients from the soil until the true secondary roots are formed. After the true secondary roots become well established they form the chief absorbing organs for the plant.

In a series of tests on the effect of temperature on germination of corn, not reported here, a marked difference was observed in the number of primary or seminal roots produced per seedling by different varieties. It was found that at the stage when the plumules were about two inches long, depending somewhat on the temperature at which the germination had taken place, no more seminal roots would come forth. Hence, all samples germinating in paper dolls were kept in the thermostats until they had reached this stage of development and a count was made of the number of seedlings per sample that showed more than one seminal root.

Previous Work

In most literature describing the process of germination in corn, no notation is made of the varietal differences occurring in the number of primary roots produced per kernel. Many authors state three or four as the usual number of primary roots developing and give no modifying statement that in certain varieties only one is produced. Probably this is due to the fact that the dent varieties, where three or four seminal roots is the usual number, are more commonly grown than are the varieties of other types, and that most of the detailed studies on the germination of corn have been made with these varieties. However, a few authorities have recognized this difference and report it in their publications.

Robbins (*4*) states "In the dent corns, four temporary roots often occur, and often in the flint and sweet corns there is but one temporary root."

Collins (*1*) was probably one of the first investigators to recognize that there are some varieties with only one seminal root. He says, "In the varieties commonly grown in the United States there are, in addition to the primary root, or radicle, from two to six additional roots that arise from the base of the cotyledons. These secondary seminal roots, though appearing somewhat later, usually equal or exceed the radicle in size. In Pueblo varieties of maize these secondary seminal roots have been absent in all seedlings thus far examined.

"Like the long mesocotyl, the simple radicle of the Pueblo varieties of maize may be looked upon as an adaptation to the extreme conditions that

*Part of thesis presented to the faculty of the Graduate School of the University of Minnesota in partial fulfilment of the requirements for the Degree of Master of Science, June, 1928.

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‡The writer wishes to express his appreciation to Professor A. C. Arny, Professor of Agronomy, University of Minnesota, for the interest which he has taken in these investigations. His advice and helpful criticism were of great assistance in planning and conducting the experiments. Thanks are due Dr. H. K. Wilson for valuable suggestions in connection with the presentation of the data.

exist where these types are grown. . . . By concentrating the energy of the seedling into a single root the latter is forced to greater depth and consequently kept in moister soil than would be the case were a number of seminal roots developed."

Wiggans (*7*) came to the conclusion that the various groups of corn do not have a regular number of seminal roots. The dent and pop corns which he tested had four seminal roots in a greater percentage of cases than any other number. The flint and sweet corns had one seminal root in more cases than any other number.

Smith and Walworth (*5*) show that individual ears possess characteristic tendencies in the number of secondary seminal roots produced per seedling. A positive correlation between high seminal root number and yield of crop was found. Correlation between high seminal root production and vigor of early growth was indicated.

Collins (*2*) questions the reliability of the results reported by Smith and Walworth.

Hutcheson and Wolfe (*3*) state that, with the unfolding of the plumule, permanent roots develop and then the temporary roots disappear.

Weaver (*6*), in an illustration of the root habit of Iowa Silver Mine corn 36 days old, shows three seminal roots arising directly from the seed and extending 2 feet in a lateral direction, which is the same distance as that of the permanent roots.

Various terms are commonly used in referring to the first root or roots produced by seeds of plants belonging to the grass family. Ordinarily, when only one root is produced by the kernel, it is referred to as the radicle. When more than one are present they are often referred to as primary, temporary, seedling or seminal roots. Collins (*1*) refers to the first root arising from the seed as the radicle and to those arising from the base of the cotyledon somewhat later than the radicle as the secondary seminal roots. Those arising from the nodes above the seed are referred to as nodal roots. This system of nomenclature is adopted in the following discussions.

Material and Methods

The samples of corn used in this experiment were obtained from the following States and Provinces: Wisconsin, Minnesota, South Dakota, North Dakota, Manitoba, Saskatchewan and Alberta. Samples of the same variety from different sources reacted very nearly alike and the results were consequently grouped according to variety.

The selfed-line samples used for the experiment reported in table 3 were secured from the Plant Genetics Section of the Division of Farm Management, Agronomy and Plant Genetics, University of Minnesota.

Where dent-flint crosses were included in the tests they were, arbitrarily, classed as dent varieties.

Investigations and Results

Five phases of secondary seminal root development were investigated: 1. Varietal differences in percentage of kernels producing secondary seminal roots. 2. Varietal differences in number of secondary seminal roots produced per kernel. 3. Differences between selfed-lines of the same variety in the production of secondary seminal roots. 4. Effect of temperature on

the production of secondary seminal roots in corn. 5. The development of secondary seminal roots in corn grown in sand.

Varietal Differences in Percentage of Kernels Producing Secondary Seminal Roots.

In Table 1 are given the percentages of kernels of different varieties producing seedlings with one or more secondary seminal roots. The counts were made on the material used in the temperature studies not reported here and are the total of all counts at the six different temperatures 9.9°, 15.5°, 22.0°, 27.0°, 30.7°, and 36.6° C. The percentages for each variety checked very closely at the different temperatures. It was observed, however, that in proportion to the development of the plumule, the secondary seminal roots made more rapid growth at the lower temperatures than at the higher ones.

The average counts reported in table 1 show a striking difference in the percentage of kernels producing secondary seminal roots in the different varieties. As a class the flint varieties showed a very low percentage, or none at all, of kernels having secondary seminal roots. The only pop variety tested behaved like the flints in this respect. The pop varieties tested by Wiggans (7) showed secondary seminal root habits like those of the dents.

Table 1. *Percentage of seedlings of different corn varieties bearing secondary seminal roots with total number counted of each variety.*

Variety	Total No. of Kernels Counted	Percentage of Kernels Producing Secondary Seminal Roots
Total		
All flint varieties	3000	1.72
Pop variety	50	0.00
All sweet varieties	150	40.66
All dent varieties	3200	86.25
Flint Varieties		
Howe's Alberta	450	0.88
Manalta	200	0.00
Manitoba	400	2.50
Gehu	650	5.23
Dakota White	850	1.64
Squaw	400	1.00
Pearl	50	0.00
Pop Variety		
Michigan Pop	50	0.00
Sweet Varieties		
Golden Bantam	50	32.00
Country Gentlemen	50	38.00
Del Maiz	50	52.00
Dent Varieties		
Manitoba Amber	400	72.50
Northwestern	1000	81.00
Minn. No. 13	1600	92.30
Minn. No. 23	100	89.00
Rustler	100	99.00

The percentage of kernels of the sweet varieties producing secondary seminal roots was 40.66 and for the dent varieties this percentage was 86.25.

Figures 1 and 2 are photographs of typical seedlings of four flint and four dent varieties, respectively. In Figure 3 are photographs of typical seedlings of one dent, one flint, and one pop variety.

Figure 1. Typical seedlings of four flint varieties. From left to right: Gehu, Manitoba, Manalta and Howe's Alberta.

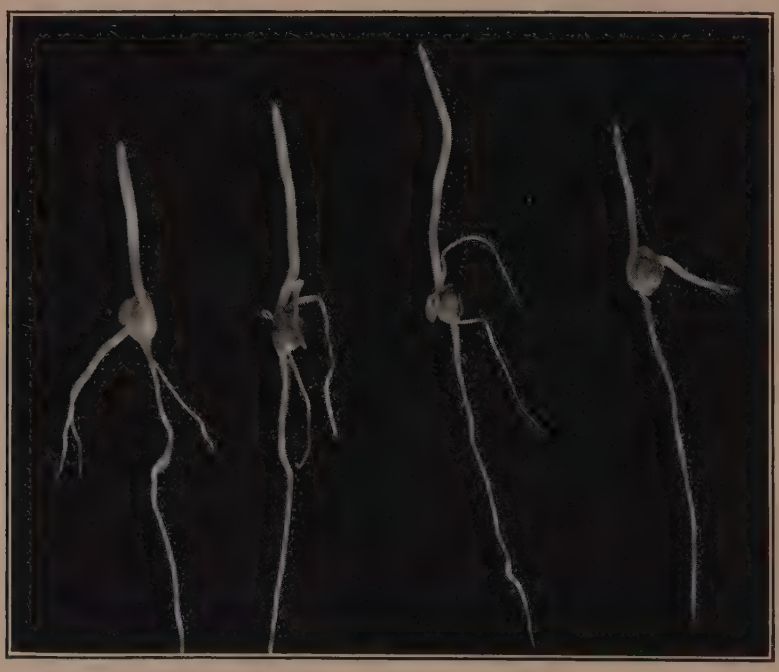

Figure 2. Typical seedlings of four dent varieties. From left to right: Rustler, Minn. No. 13, Golden Glow (Cold Resistant) and Minn. No. 23.

Figure 3. Typical seedlings of one dent (Rustler), one flint (Dakota White), and one pop (Michigan Pop) variety.

The percentage of kernels which produced secondary seminal roots was considerably lower in the Manitoba Amber variety than for the average of all dent varieties. It is interesting to note in this connection that the Manitoba Amber variety was developed from a cross between Manitoba Flint and Northwestern Dent. Of the dent varieties, Northwestern stands next to Manitoba Amber in the percentage of kernels producing secondary seminal roots. The origin of this variety is not definitely known but these results add evidence to the belief that it was developed from a flint-dent cross.

Varietal Differences in the Number of Secondary Seminal Roots Produced per Kernel

In order to obtain further information on the secondary seminal root habit of commercial varieties, an additional series of samples was tested particularly for the development of this character. In addition to determining the percentage of seedlings producing one or more secondary seminal roots, counts were also made of the number produced by each seedling. The results are given in table 2.

Of the five flint varieties tested, 95.4 per cent of the kernels produced no secondary seminal roots, 2.6 per cent produced only one, 0.83 per cent produced two, 0.83 per cent produced three, and 0.43 per cent produced four per kernel.

TABLE 2. *Number of kernels producing* 0, 1, 2, 3, 4, 5, 6, 7 *and* 8 *secondary seminal roots in tests of* 50 *kernels from each of* 20 *different varieties or strains of varieties with mean number produced per kernel for each.*

Variety	Total No. germinated	Number of secondary seminal roots per seedling									Mean
		0	1	2	3	4	5	6	7	8	
Average in per cent :											
All flint varieties		95.4	2.6	.83	.83	.43					
All sweet varieties		44.2	25.0	19.3	8.4	2.9	.8	.3			
All dent varieties		7.9	7.9	21.5	26.9	20.2	11.1	2.9	.9	.3	
Total in numbers :											
All flint varieties	240	229	6	2	2	1					0.071
All sweet varieties	1283	566	309	251	112	29	10	6			1.057
All dent varieties	638	50	50	136	169	132	74	19	8	2	2.958
				Flint Varieties							
Gehu	49	49									0.000
Dakota White	49	48	1								0.020
Longfellow	48	46	1	1							0.062
Triumph	48	44	2	1		1					0.104
King Philip	46	42	2		2						0.173
				Sweet Varieties							
Del Maiz	1233	543	298	243	107	26	10	6			1.034
Golden Bantam	50	23	11	8	5	3					1.080
				Dent Varieties							
Golden Glow x Howe's Alta Flint	49	10	10	24	5						1.694
Minn. No 13 x Howe's Alta Flint	48	2	7	13	13	9	4				2.666
Silver King (King's Cross)	50	6	6	9	11	10	6	2			2.780
Minn. No. 23	47	3	3	10	14	14	3				2.893
Northwestern	49	13	5	9	3	16	3				2.265
Northwestern (Crookston strain)	49	3	1	7	17	13	7		1		3.163
Golden Glow	50	3	3	13	13	9	7	1	1		3.040
Golden Glow Cold Resistant	50	1	3	6	18	11	11				3.360
Minn. No. 13 (Standard)	50	2	3	8	19	10	6	1	1		3.180
Minn. No. 13 (Haney's strain)	50	3	2	10	15	9	4	2	3	2	3.120
Rustler	48	1	4	9	12	10	8	4			3.375
Murdock	49	1	2	10	16	8	5	7			3.449
Wisconsin No. 25	49	2	1	8	13	13	10	2			3.469

Fifty-five per cent of the kernels of the sweet varieties produced one or more secondary seminal roots. Of these 25.0 per cent produced one, 19.3 per cent produced two, 8.4 per cent produced three, 2.9 per cent four, 0.8 per cent five, and 0.3 per cent produced six secondary seminal roots per kernel.

The frequency distribution in the average of the dent varieties was markedly different from that of the flints and sweets. Ninety-two per cent of the kernels in this group produced one or more secondary seminal roots. Of these the greatest percentage was found in the class with three secondary seminal roots per seedling, with a gradual falling off on either side of this number. This agrees with Wiggans' results for the dent varieties (*7*).

The mean number of secondary seminal roots per seedling for each of the three groups is shown in the last column in the first section of the table. The number for the flints is very low, that of the dents is relatively high, and that of the sweets is intermediate.

The smallest mean number of secondary seminal roots per seedling were found in the Gehu and Dakota White varieties and the largest number in Rustler, Murdock, and Wisconsin No. 25 varieties. In all tests the secondary seminal roots produced by the Rustler variety showed greater vigor than those of other varieties.

The first two samples listed under dent varieties, Golden Glow × Howe's Alberta Flint, and Minnesota No. 13 × Howe's Alberta Flint are F_1 generations of dent-flint crosses. The fact that they produced roots more like the average dents, indicates that the character for the presence of secondary seminal roots is dominant over the character for the absence of these roots.

Differences Between Selfed Lines of the Same Variety in the Production of Secondary Seminal Roots

To determine how selfed-lines of corn of the same variety would behave with regard to this root character, the tests reported in table 3 were conducted.

Samples of 50 seeds were obtained from the Section of Plant Genetics of the Division of Farm Management, Agronomy and Plant Genetics, University Farm, St. Paul, of 5 selfed-lines of King Philip and Longfellow flint, and 13 selfed-lines of North-western, Minnesota No. 13 and Rustler dent varieties. Each sample was divided into two equal lots and from the series of results of the duplicate lots the reliability of the experiment was calculated by "Student's" method. Odds of 3.68:1 were obtained, which indicate that the differences were not significant.

The average results of the 5 selfed-lines of the flints agree with the average of all flint varieties. The average results of the 13 selfed-lines of dents similarly agree with the average of all dent varieties (tables 1 and 2).

Line 63-2 of the Northwestern variety, like the lines of the flint varieties, developed practically no secondary seminal roots. The indication is that this character is inheritable but not always associated with the character of flintiness nor dependent on the presence of the flinty character for its expression. Theoretically, then, it should be possible to produce a flint corn which will develop secondary seminal roots like those in the ordinary dent varieties.

TABLE 3. *Number of kernels producing 0, 1, 2, 3, 4, 5, 6, 7, and 8 secondary seminal roots in duplicate tests of 25 kernels each from 18 selfed lines of 2 varieties of flint and 3 of dent corn with total numbers for the two types, mean number per kernel for each sample and average mean number per kernel for each selfed line.*

Variety	Culture No.	No. of years selfed	Sample No.	Total No. germinated	Number of secondary seminal roots per seedling									Mean	Average
					0	1	2	3	4	5	6	7	8		
Average in per cent: All flint varieties					85.1	9.6	5.4								
All dent varieties					12.5	7.4	18.7	30.5	21.8	6.7	1.9	.3	.1	0.1639	
Totals in number: All flint varieties				242	206	23	13							2.652	
All dent varieties				626	78	46	117	191	137	42	12	2	1		
					Flint Varieties										
King Philip	71A-1	9	1	23	22	1								0.043	
" "	"	9	2	25	24	1								0.041	0.042
" "	29B-1	9	1	24	22	1	1							0.125	
" "	"	9	2	25	25									0.000	0.062
Longfellow	70A-1	6	1	25	25									0.000	
"	"	6	2	24	19	5								0.208	0.104
"	26A-2	6	1	23	17	1	5							0.478	
"	"	6	2	23	17	5	1							0.304	0.361
"	27B-1	6	1	25	17	5	3							0.440	
"	"	6	2	25	18	4	3							0.400	0.420
					Dent Varieties										
Northwestern	63-2	6	1	25	24	1								0.041	
"	"	6	2	24	22	2								0.083	0.062
"	66B-1	9	1	24	4	5		5	7	2	1			2.666	
"	"	9	2	24	5	4	4	5	5	1				2.166	2.416
"	68A-1	10	1	25	1	2	4	9	5	4				3.080	
"	"	10	2	25	1	2	1	5	10	3	1	2		3.760	3.420
"	21-1	9	1	24	1	2	2	5	8	4	2			3.541	
"	"	9	2	24	3	3	8	9	1					2.083	2.812
Minnesota No. 13	11B-4	7	1	25			5	13	4	2	1			3.240	
" "	"	7	2	25			2	12	9	2				3.440	3.340
" "	43-5	7	1	25			2	7	9	6	1			3.880	
" "	"	7	2	25			2	14	8	1				3.320	3.600
" "	44-3	7	1	24	2	2	16	13	1					1.958	
" "	"	7	2	24	5	2	15	2						1.583	1.770
" "	49A-1	8	1	20	4	7	4	3	2					1.600	
" "	"	8	2	23	2	5	4	6	6					2.391	1.995
Rustler	16A-1	8	1	25	1	1	1	5	12	4	1			3.680	
"	"	8	2	23			3	5	8	4	2		1	4.043	3.861
"	19A-1	10	1	25		1	4	9	7	3	1			3.400	
"	"	10	2	24			4	9	8	2	1			3.458	3.429
"	51A-1	6	1	23		3	6	11	3					2.608	
"	"	6	2	24		1	12	11						2.417	2.512
"	54B-2	6	1	23			2	10	9	1	1			3.521	
"	"	6	2	24	1		2	11	7	3				3.333	3.427

Effect of Temperature on the Production of Secondary Seminal Roots in Corn

In the experiment on the effect of temperature, not reported here, the germination test at the temperature of 7.0° C. was terminated at the end of 60 days, germination percentages read and the viability of the kernels that had not germinated, and the vitality of those that had, determined by transferring them to a temperature of 26° C. At the time the seeds were transferred to a higher temperature, none of the kernals that had germinated showed any secondary seminal roots. Five days later when the viability counts were made, the percentage of seedlings bearing secondary seminal roots was recorded. In table 4 the readings of the secondary seminal roots are given and compared with the counts for the same samples when germination took place at the temperature of 26° C. without previously subjecting the kernels to a temperature of 7° C. for 60 days.

Table 4. *The effect of keeping corn seeds of different varieties in paper dolls at 7°C for 60 days and then at 26°C for 5 additional days on the development of the secondary seminal roots, as compared to germination at 26°C for 6 days without previously exposing to temperature of 7°C.*

Variety	No. samles tested*	% of seedlings with sec. seminal roots after germinating for 6 days at 26°C.	% of seedlings with sec. seminal roots after exposure for 60 days at 7°C and 5 additional days at 26°C.
Average			
All flint varieties	28	3.64 ± .12	42.95 ± 1.04
All dent varieties	38	93.32 ± 2.50	90.83 ± 1.83
		Flint Varieties	
Howe's Alberta	4	2.0 ± .10	45.9 ± 1.84
Manalta	2	0.0 ± .00	47.2 ± 2.68
Manitoba	3	2.0 ± .12	60.0 ± 2.79
Gehu	5	4.8 ± .22	41.8 ± 1.50
Dakota White	6	1.6 ± .07	28.9 ± .95
Early Squaw	1	1.0 ± .10	23.4 ± 1.88
Pearl	1	0.0 ± .00	52.1 ± 4.19
Longfellow	2	2.0 ± .14	65.9 ± 3.75
King Phillip	2	15.0 ± 1.08	20.3 ± 1.15
Triumph	1	8.0 ± .82	25.7 ± 2.07
Rainbow	1		61.3 ± 4.93
		Dent Varieties	
Minn. No. 13 x Howe's Alberta	1	96.0 ± 9.82	100.0 ± 8.04
Golden Glow x Howe's Alberta	1	80.0 ± 8.18	55.5 ± 4.46
Manitoba Amber	2	82.0 ± 5.93	75.3 ± 4.28
Northwestern	9	88.4 ± 3.01	90.9 ± 2.44
Minn. No. 13	8	97.6 ± 3.53	86.4 ± 2.46
Alta	1	100.0 ± 10.27	97.6 ± 7.85
Brookings No. 86	2	98.5 ± 7.12	98.8 ± 5.62
Minn. No. 23	2	96.0 ± 6.94	97.5 ± 5.54
Rustler	2	98.0 ± 7.08	93.3 ± 5.30
Silver King	1	88.0 ± 8.90	85.7 ± 6.89
Wisconsin No. 7	1		83.3 ± 6.70
Murdock	1	98.0 ± 10.02	100.0 ± 8.04
Wisconsin No. 25	1	96.0 ± 9.82	100.0 ± 8.04
Wisconsin No. 12	1		97.2 ± 7.82
Golden Glow	1	94.0 ± 9.61	94.5 ± 7.60
Golden Glow Cold Resistant	4	94.0 ± 4.81	97.3 ± 3.91

*Each sample consisted of 50 kernels.

In the first column are given the numbers of samples tested. In the second column appear the percentages of seedlings that produced secondary seminal roots in 6 days at 26° C. In the last column are recorded the percentages of seedlings which produced secondary seminal roots in 5 days at 26° C. when the seeds had previously been held at 7° C. for 60 days.

The first two lines give the results for the average of all flint and all dent varieties, respectively. Below these the results for each of the flint and the dent varieties are reported.

Comparing the figures for the average of all flint varieties given in the first line and last two columns of the table, a difference is apparent. At the temperature of 26° C. only 3.64 per cent of the kernels of the flint varieties developed secondary seminal roots. Exposing the kernels to 7° C. for 60 days under germinating conditions and then removing them to a temperature of 26° C. for 5 days, resulted in 42.9 per cent of the seedlings producing secondary seminal roots.

For the dent varieties 93.3 per cent of the kernels produced secondary seminal roots at 26° C, and 90.83 per cent when exposed to the temperature of 7° C. for the 60 days previously.

The results indicate that exposure to cold environmental conditions induces the secondary seminal roots to develop in the flints. It is possible that a shorter period of exposure to similar conditions would bring about the same effect.

The secondary seminal roots induced to develop in the flints by this treatment were more slender and less vigorous than those of the dents. It was also observed that in a large percentage of seedlings of the flint varieties the radicle had died away during the exposure to low temperature, while the plumule had remained alive. Probably the secondary seminal roots were developed in the flints in an effort to substitute the radicle.

Development of Secondary Seminal Roots in Corn Grown in Sand

A few attempts have been made to show the influence of the presence or absence of the secondary seminal roots in the corn seedling on the development of the plant. Smith and Walworth (*5*) present data showing a positive correlation between high seminal root number and yield of crop and cite evidence that high seminal root number tends to enhance vigor of growth. Collins (*1*) associates the absence of secondary seminal roots in Hopi maize with a more deeply penetrating radicle.

A number of varieties were planted in the greenhouse in sand at a series of depths ranging from 2 to 10 inches. Twenty-three days after planting, observations were made on the development of the radicle and secondary seminal roots.

The dent varieties developed many secondary seminal roots, while the flint varieties produced none. Several of the Manitoba Amber variety produced a radicle only, like the flints.

The longest secondary seminal root was found in the Northwestern variety, planted 8 inches deep. It measured 12.5 inches. The radicle of this seedling measured 12 inches. The true secondary, or nodal roots, were shorter. The longest radicle, measuring 18 inches, was found in the Squaw variety planted 8 inches deep.

Figure 4. Seedlings of Manitoba Amber and Dakota White planted 8 and 10 inches deep, showing length of mesocotyl and difference in secondary seminal root development.

Figure 5. Seedlings of Northwestern Dent and Howe's Alberta Flint, planted 8 and 10 inches deep, showing length of mesocotyl and the difference in secondary seminal root development.

In Figures 4 and 5 the seminal root development can be seen as it appeared at this time. In washing the seedlings the finer rootlets and root hairs were destroyed, but the fibrous nature of those remaining is shown in the photographs. Only one of the two Manitoba Amber seedlings in Figure 4 had the secondary seminal roots, while neither of the Dakota White seedlings show their development. The true secondary, or nodal roots, are shown at the upper end of the mesocotyl. Figure 5 shows a comparison in seminal root systems between Northwestern and Howe's Alberta Flint.

The length and profusion of the secondary seminal roots as observed 23 days after planting, lead to the belief that the presence of these roots probably aids the seedling under conditions of low soil moisture content. A single seminal root may penetrate to greater depths but the distribution of 2 to 8 roots penetrating to about two-thirds the depth of a single seminal constitutes a greater absorbing area for the seedling. Seedlings with secondary seminal roots should be able to withstand a reduction in moisture content of the upper layer of soil more satisfactorily than those without them. Further investigations testing this assumption will be conducted.

Summary and Conclusions

1. Corn types differed in seminal root habit. The flints and Michigan pop usually produced no secondary seminal roots. Of the sweet varieties 60 per cent and of the dent varieties 90 per cent of the kernels produced secondary seminal roots.

2. The kernels of the sweet varieties tested produced no secondary seminal roots more often than any other number. The kernels of the dent varieties produced 3 secondary seminal roots more often than any other number.

3. One selfed-line of Northwestern dent was found which produced practically no secondary seminal roots.

4. Exposing the kernels to a temperature of 7° C. and under otherwise germinating conditions for 60 days and then transferring them to a temperature of 28° C. for 5 days induced about 40 per cent of the flint seedlings to develop secondary seminal roots.

5. The secondary seminal roots form an extensive root system for the corn seedling.

LITERATURE CITED

1. Collins, G. N. A drought-resisting adaptation in seedlings of Hopi maize. Jour. Agr. Res. 1: 293-302. 1914.
2. ———— Yield and the number of seminal roots in maize. Jour. Amer. Soc. Agron. *19*: 466-467. 1927.
3. Hutcheson, T. B. and Wolfe, T. K. The production of field crops. McGraw-Hill Book Company, Inc., N.Y. 495 pages. 1924.
4. Robbins, W. W. The botany of crop plants. Sec. Ed. P. Blakiston's Son & Co., Philadelphia. 674 pages.
5. Smith, L. H. and Walworth, E. H. Seminal root development in corn in relation to vigor of early growth and yield of crop. Jour. Amer. Soc. Agron. *18*: 1113-1120. 1926.
6. Weaver, John E. Root development of field crops. McGraw-Hill Book Company, Inc. N.Y. 291 pages. 1926.
7. Wiggans, R. G. The number of temporary roots in cereals. Jour. Amer. Soc. Agron. *8*: 31-37. 1916.

CONCERNING THE C.S.T.A.

The August issue of this journal will contain a complete report of the ninth annual convention of the Canadian Society of Technical Agriculturists, held at Winnipeg, Man., June 12-15, 1929. The presidential address of Dr. E. S. Archibald, the annual report of the General Secretary of the Society, the reports of standing committees adopted at the convention, the resolutions passed, and much other information of general interest will be covered in this report. There will also be published in the next issue some of the lectures which were given during the convention.

The August issue will complete Volume IX of *Scientific Agriculture,* and will therefore include a subject and author index for the year.

A few of the more important items of business transacted during the annual convention, or at meetings of the Board of Directors, were as follows:—

1. The following recommendations were made by a special committee on Publications:—

(a) That papers given at meetings of affiliated societies should be edited carefully by the Secretary of that Society or by the author and should be subject to approval by the Editorial Board of *Scientific Agriculture* before publication.

(b) That the news section regarding C.S.T.A. members and locals be enlarged to a minimum of about four pages and that this be printed as a separate leaflet and sent to members with each issue of the magazine. It is suggested that the work of collecting notes and news items could be facilitated by getting each local to appoint a correspondent who would be responsible for forwarding information of interest to the editor

(c) That one hundred reprints of articles should be given free only to contributors who are members of the C.S.T.A. and fifty to other contributors.

(d) That it would be advantageous to have printed on the back binding of each issue the name of the journal, volume number, and month of issue.

(e) That the present high standing of the journal should be maintained and improved upon, if finances permit. The committee is of the opinion that a leaflet, prepared by some competent person, dealing with the best usages and practices in the preparation of scientific articles would be of service to the membership if placed in their hands. Two or more good papers on this subject have appeared recently. In this connection attention should be drawn to the virtues of conciseness, and also the economies that could be effected thereby.

(f) That notices of new publications relating to agriculture, issued by Canadian universities, Agricultural Colleges and Experimental Farms, be given in the journal as soon as possible after they are available.

Commencing with Volume X in September, 1929, an effort will be made to put into effect some of the recommendations made by the above committee. Whether finances will permit the introduction of all of the suggested changes cannot be predicted at this date, but those suggestions relating to editorial policies can probably be adopted at once.

In regard to recommendation No. 5 it was felt by members of the committee that a number of the articles now being published in this journal could be abbreviated to good advantage and thereby permit the publication of a larger number of articles per annum. Since the journal is now becoming somewhat congested with material, and articles are having to be held over three or four months before publication is possible, the condensing of lengthy articles would do much to relieve this situation.

2. Mr. Fred Pugh of the T. Eaton Company Research Bureau, Winnipeg, Man., was elected to Honorary Membership in the Society.

3. Professor W. R. Graham, Ontario Agricultural College, Guelph, Ont., Dean E. A. Howes, University of Alberta, Edmonton, Alta., and Dr. W. P. Thompson, University of Saskatchewan, Saskatoon, Sask., were awarded Fellowships by the Society.

4. The five T. Eaton Company scholarships for 1929, amounting to $600.00 each, were awarded to the following:—

ROBERT HENRY BEDFORD (Alberta, 1926, B.Sc., 1928, M.Sc.). Research subject, "Classification of cellulose-destroying organisms of Canadian soils," to be taken at McGill University.

NEILSON A. DRUMMOND (McGill, 1928, B.S.A.). Research subject, "Marketing of Canadian livestock," to be taken at the University of Toronto.

KENNETH ARCHIBALD HARRISON, (Toronto, 1924, B.S.A., McGill, 1926, M.Sc.). Research subject "A study of black knot and its control in commercial plum orchards," to be taken at the University of Toronto.

JOHN NICHOLSON WELSH, (McGill, 1922, B.S.A.). Research subject "A study of several genetic characters in oats," to be taken at the University of Alberta.

WILFRED HORNSBY WRIGHT, (Toronto, 1912, B.S.A.). Research subject, "A study of seed-borne diseases," to be taken at the University of Toronto.

5. The Board of Directors of the C.S.T.A. at a meeting held on June 15, appointed Mr. Henry E. Lefèvre to the position of French Secretary of the Society and French Editor of *Scientific Agriculture*, the appointment to date from July 1st, 1929. Mr. Lefèvre succeeds Professor H. M. Nagant, who has been obliged to relinquish the position on account of poor health.

6. The Board of Directors decided to hold the 1930 convention of the Society at the Ontario Agricultural College, Guelph, Ont.

7. Dr. Robert Newton of the University of Alberta presented a tentative report on the survey which he has recently completed on graduate facilities in agriculture in Canada. His final report will be published shortly by the Society and mailed to every member in good standing.

8. The following committees were appointed for the current year, the Chairman of each committee being named first:—

Executive Council: J. P. Sackville, W. T. Macoun, Georges Bouchard, M.P., L. H. Newman, H. G. Crawford, J. C. Fuller, J. B. Fairbairn, P. N. April, A. McTaggart.

Research: A. Cairns, W. Sadler, Robert Newton, W. R. Graham, W. H. Brittain, A. M. Shaw, C. H. Goulden.

Agricultural Policies: E. A. Howes, F. H. Auld, W. B. Roadhouse, H. Barton, E. S. Archibald, G. H. Clark, J. H. Grisdale.

Economics and Marketing: J. E. Lattimer, F. M. Clement, H. S. Fry, J. A. Carroll, H. S. Arkell.

Educational Policies: L. S. Klinck, C. Eric Boulden, L. C. Roy.

General Membership: H. G. Crawford, W. M. Fleming, J. M. Manson, W. W. Thomson, P. M. Simmonds, F. E. Foulds, A. W. Baker, G. H. Dickson, R. R. McKibbin, P. H. Vezina, Leo Brown, C. E. Boulden, Stanley Wood, B. F. Tinney.

Affiliations: J. M. Swaine, R. Summerby, F. L. Drayton, A. Savage, J. C. Steckley, H. Barton, R. R. McKibbin.

Finance: J. B. Harrington, J. H. Tremblay, J. B. Fairbairn.

Progress: D. H. Galbraith, H. R. Hare.

Membership: W. R. Leslie, H. G. Crawford, P. N. April.

Ballot: L. C. McOuat, E. S. Archibald.

Auditors: H. C. Crawford, G. LeLacheur.

Representative on Council of A.A.A.S.: Fred. H. Grindley.

Applications for Membership

The following applications for regular membership have been received since June 1, 1929:—

Barnes, S. (Alberta, 1921, B.S.A.) Swift Current, Sask.

Hollingshead, E. L. (Saskatchewan, 1923 B.A., 1926 M.A., California, 1929 Ph.D.) Winnipeg, Man.

Hudon, Marc H. (Laval, 1925, B.S.A., Cornell, 1928, M.Sc.) Ottawa, Ont.

Johnson, A. E. (McGill, 1929, B.S.A.) Halifax, N.S.

Lindsay, W. E. (McGill, 1929, B.S.A.) Ottawa, Ont.

Robinson, G. Hugh (Saskatchewan, 1929, B.S.A.) North Portal, Sask.

Sigfusson, S. J. (Manitoba, 1914, B.S.A.) Brandon, Man.

Townsend, T. L. (Manitoba, 1923, B.S.A.) Winnipeg, Man.

Notes and News

B. Bourgault (Laval '14) and P. E. Lafresniere (Montreal '23), members of the staff of the Dominion Seed Branch, formerly at Quebec, P.Q., are now located in the Labelle Building, St. Catherine Street East, Montreal, P.Q.

T. W. Grindley (Alberta '23) recently received the degree of Ph.D. in agricultural economics from the University of Minnesota.

A. R. Prince (Acadia '22), Provincial Biologist for Nova Scotia, has changed his address to 177 Queen Street, Truro, N.S.

John Walker (Alberta '24), formerly Assistant to the Superintendent at the Indian Head Experimental Farm, is joining the staff of the Division of Extension, Department of Agriculture, Winnipeg, Man., on July 1st, 1929.

R. W. Brown (Toronto '13), who has been taking graduate work in dairy plant management and dairy bacteriology at the Iowa State College, has now resumed his duties as Professor of Dairy Husbandry at the Manitoba Agricultural College, Winnipeg, Man.

F. L. Drayton (McGill '14) has returned to Ottawa from Cornell University, where he has been taking graduate work, and has resumed his duties as Plant Pathologist at the Central Experimental Farm.

R. C. Russell (Saskatchewan '24), who has been taking graduate work in plant pathology and mycology at the University of Toronto, has returned to the Dominion Laboratory of Plant Pathology, Saskatoon, Sask., as Assistant Plant Pathologist.

L. A. Hietanen (Toronto '27) has been taking a course at the Ontario College of Education in Toronto, but has now returned to Port Arthur. His mailing address is P. O. Box 435, Port Arthur, Ont.

J. K. King (McGill '13) is now with the Canadian Co-operative Livestock Producers Limited, Duke and George Streets, Toronto 2, Ont.

J. A. Martin (Montreal '28) is Assistant County Agriculturist at Campbell's Bay, P.Q.

Kenneth Cox (Toronto '24), who has been taking graduate work at Macdonald College in agronomy, has resumed his duties as Assistant to Superintendent, Dominion Experimental Farm, Nappan, N.S.

Robert H. Bedford (Alberta '26) is temporarily at the Fisheries Experimental Station, Prince Rupert, B.C.

B. G. Montserin (McGill '27) is at the Horticultural Experiment Station, Vineland Station, Ont., for the summer months.

G. T. Jackson (Toronto '25) is now Sales Representative of Creamery and Dairy Equipment, with the De Laval Company. His mailing address is 2178 Queen Street East, Toronto, Ont.

N. S. Golding (Toronto '14) has received the degree of Ph.D. from the Iowa State College where he has been completing his course since last April. He expects to resume his duties as Associate Professor of Dairying at the University of British Columbia about the beginning of August.

L. D. Mallory (British Columbia '27) recently received the degree of M.S.A. in agricultural economics from the University of British Columbia.

S. M. Walford (McGill '26), who for the past two years has been R.O.P. Inspector, Indiana R.O.P. Breeders' Association, is joining the Poultry Extension Department staff at Purdue University, Lafayette, Ind. U.S.A.

J. A. Godbout (Laval '13), Professor of Animal Husbandry at the Agricultural School, Ste. Anne de la Pocatière, P.Q., has been elected a member of the Provincial Legislature for the County of L'Islet.

H. D. Mitchell (McGill '15), has been appointed to the staff of the Division of Extension and Publicity, Central Experimental Farm, Ottawa. He took up his duties on June 1st, 1929, and is in charge of the information booth at the Central Farm.

The Civil Service Commission, Ottawa, Ont., is advertising the position of Animal Husbandman (bilingual) for the Dominion Experimental Farms Branch, at an initial salary of $2,040 per annum, with increases at the rate of $120 per annum up to a maximum of $2,520. Applications must be in the hands of the Secretary of the Commission not later than July 18th, 1929.

The attention of members is directed to the recent publication of a new edition of the C.S.T.A. "Who's Who", the first edition of which was published in 1924. The new volume, which is 240 pages in size, contains the biographies, academic training and professional experience of 1,080 members of the Society and is a very useful reference book. At the time of writing about 450 members have sent in orders for the "Who's Who" at the special price of $2.00, postage paid. Only 60 copies remain to be sold and these will be disposed of as orders are received. No copies will be available after July 31st.

Dr. F. A. E. Crew of the University of Edinburgh, who delivered three addresses during the recent C.S.T.A. Convention, sailed for Glasgow from Montreal on June 22nd. A meetin gof those in eastern Canada who are interested in animal genetics was held in the C.S.T.A. headquarters, Ottawa, on June 21st, so that those in attendance might have an opportunity of meeting Dr. Crew and discussing some of their problems with him. The meeting was conducted by Dr. J. H. Grisdale, Deputy Minister of Agriculture for Canada.

Since the opening of the Society's headquarters on May 10th a large number of members have registered in the visitors' book and several meetings have been held in the Board Room. Members coming to Ottawa are urged to visit their headquarters and make free use of them while in the Capital.

The Economics Group of the C.S.T.A. is giving consideration to the adoption of a new name for the group—the Canadian Society of Agricultural Economists—believing that such action would bring into the group a number who are not now members of the C.S.T.A. The idea is quite a good one and it is to be hoped that it will be put into effect. The C.S.T.A. is very willing to foster such organizations and to help them in every way possible.

Local branch secretaries are reminded that notes concerning their members, reports of their activities, and similar news items will be welcomed by the General Secretary at any time. Whether such items will remain a part of *Scientific Agriculture,* or be printed separately, will be decided during the next two months. In any case, every member is interested in learning of the activities of his fellows, and we are largely dependent upon local secretaries for this information.

All members are urged to notify the General Secretary of changes in their position or address.